Chapter 9

Celestial Observations and Sight Reduction Methods

Introduction

In this chapter you will learn the methods that are necessary to complete a day's work in navigation. These include several ways of finding gyrocompass error, reducing sunlines and moonlines, finding latitude by LAN or Polaris, and reducing sights of stars and planets.

We've already covered the basics of celestial navigation in chapter 6. You may want to occassionally refer back to that material to have a clearer understanding of this material. We will discuss the procedure aspect of performing and reducing celestial observations only. As you become more familiar with this subject, you are advised to increase your knowledge by studying references such as *Dutton's Navigation* and *Piloting* and *Bowditch* Pub No. 9.

Objectives

The material in this chapter will enable the student to:

- Determine gyrocompass error by azimuth of the Sun and Polaris, and amplitude of the Sun.
- Reduce sights taken on the Sun, Moon, stars, and planets using H.O. 229, *Sight Reduction Tables for Marine Navigation*, and the *Nautical Almanac*.
- Reduce sights taken on the stars using H.O. 249, *Sight Reduction Tables for Air Navigation* and the *Air Almanac.*
- Determining latitude by local apparent noon.
- Plot celestial LOPs based on assumed positions.

Methods For Finding Gyrocompass Error

Introduction

There are three celestial methods used by QMs for finding gyrocompass error. They are:

- Azimuth of the Sun
- Azimuth of Polaris
- Amplitude of the Sun

In each case, you are required to gather data for use in computation. This data may be in the form of sights from the sextant, time in GMT, DR Lat. and Long., and so forth. For each celestial method, we will begin with gathering the necessary data and then working the solutions.

Azimuth of the Sun

You must know the following values to determine gyrocompass errror by azimuth:

Gathering Data

- Time of the actual observation
- Date of the observation
- DR position at the time of observation
- Azimuth (gyro bearing of the Sun)

Rule: Due to the elevation of the Sun, azimuths should be taken in mid-morning or mid-afternoon.

Use the following table to gather the data to work the azimuth solution. You must have a recorder present to mark and record the exact time of the observation

Step	Action
1.	Obtain a time tick from WRN-6 or chronometer with a stopwatch.
2.	Break out and place the azimuth circle on the gyro repeater closest to the Sun.
3.	Align the Sun in the reflecting mirror in a manner so that the rays reflect back through the prism housing and onto the compass card.
4.	When each spirit level is leveled, mark the time and record the reflected gyro bearing from the compass card to the nearest 0.1°. **Note:** This is a difficult procedure in heavy seas; however, if the azimuth circle is not level, errors will occur.
5.	Repeat steps 4 and 5 a minimum of three times.

Gathering Data

Now that we have three good observations, we need only to find the DR position for each obvservation to have the data we need to find the azimuth of the Sun. We will work an example problem using OPNAV strip form AZIMUTH BY PUB 229. For brevity, we'll work on one observation only. In actual practice, it's faster to work out all three at the same time by placing the strip form on the left and working the three observations in the next three columns. The purpose of taking at least three observations is to allow us to find errors when taking observations and averaging gyro error. This process normally provides the best results in determining total gyro error.

Besides the data from the observation, you'll need the *Nautical Almanac* and Pub 229 to solve the problem.

From the strip form and publication we will find out exactly what the gyro bearing *should* read, then we will compare that value to the actual gyro bearing from the observation. The result will be our gyro error.

Example Problem

For our example problem, we will assume that we have gathered the following data:

Date:	19 Nov 84
DR Lat.:	33° 37' N
DR Long.:	112° 39' E
ZT:	15h 42m 22s
Gyro Brg:	231.6°

On the following pages, you will find the page laid out with the blank strip form on the left, the action steps in the middle, and the result on the right.

Azimuth of the Sun, Continued

OPNAV 3130/ Azimuth by 229	**ACTION**	**Completed Strip Form**
Date:	Enter the date.	19 NOV 84
DR Posit	Enter the DR position.	33°37'N - 112°39'E
Body	Enter the name of the body observed.	Sun
GMT	Enter the time GMT.	07h42m22s
GHA(h)	Enter the GHA hour value from the *Nautical Almanac* (fig. 9-1)	288° 38.9'
Increment (m/s)	Enter the minutes and seconds value from the *Nautical Almanac* (fig. 9-2).	10° 35.5'
Total GHA	Add GHA(h) and increments (m/s).	299° 14.4'
DR Long +E, -W (+ - 360° if needed)	Enter the DR Longitude, add east or subtract west.	112° 39.0'E
LHA	LHA= Total GHA +E or -W DR Long.	51° 53.4'
Tab Dec	Enter the tabulated declination for 07 hours on the Sun column from the *Nautical Alamanac.*	S 19° 31.2'
d# / D Corr^{n}	The d# is found at the bottom of the Sun Dec column, in this case it is +0.6. It is assigned a + because Dec is increasing (0700= 19°31.2 0800= 19°31.8). You MUST assign a + or - to the d#. The D corr is found on the Increments and Corrections page for 42m 22s. Look under the *v* or *d* column for the d# (0.6) and record the Corr^{n} value (0.4). The D Corr^{n} assumes the same sign as the d# .	+0.6 / +0.4
True Dec	Apply the D Corr^{n} to Tab Dec	S 19° 31.6
DR Lat same or contrary	Enter the whole degree of latitude and determine if it is named (N or S) as True Dec In this case, Lat. is N and Dec is S. so it is contrary.	N 33° contrary

Up to this point, we have worked the strip form to obtain three values, LHA, True Dec., and DR Latitude. We now have everything we need to enter Pub 229. Pub 229 is entered using whole degrees of Lat., LHA, and Dec. only. We will also interpolate the leftover values using Pub 229.

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	G.M.T.	SUN G.H.A.	SUN Dec.	MOON G.H.A.	v	MOON Dec.	d	H.P.
	d h	° ′	° ′	° ′	′	° ′	′	′
	17 00	183 46.2	S18 58.5	258 20.6	9.9	N14 55.5	13.4	59.0
	01	198 46.1	59.1	272 49.5	9.9	14 42.1	13.5	59.1
	02	213 46.0	18 59.7	287 18.4	10.0	14 28.6	13.6	59.1
	03	228 45.8	19 00.3	301 47.4	10.0	14 15.0	13.6	59.1
	04	243 45.7	00.9	316 16.4	10.1	14 01.4	13.7	59.1
	05	258 45.6	01.6	330 45.5	10.0	13 47.7	13.9	59.2
	06	273 45.5	S19 02.2	345 14.5	10.2	N13 33.8	13.9	59.2
	07	288 45.4	02.8	359 43.7	10.1	13 19.9	14.0	59.2
S	08	303 45.2	03.4	14 12.8	10.2	13 05.9	14.1	59.2
A	09	318 45.1	·· 04.0	28 42.0	10.2	12 51.8	14.1	59.3
T	10	333 45.0	04.6	43 11.2	10.3	12 37.7	14.3	59.3
U	11	348 44.8	05.2	57 40.5	10.3	12 23.4	14.3	59.3
R	12	3 44.7	S19 05.8	72 09.8	10.3	N12 09.1	14.4	59.3
D	13	18 44.6	06.4	86 39.1	10.3	11 54.7	14.5	59.3
A	14	33 44.5	07.0	101 08.4	10.4	11 40.2	14.5	59.4
Y	15	48 44.3	·· 07.6	115 37.8	10.4	11 25.7	14.6	59.4
	16	63 44.2	08.2	130 07.2	10.5	11 11.1	14.7	59.4
	17	78 44.1	08.8	144 36.7	10.5	10 56.4	14.8	59.4
	18	93 44.0	S19 09.4	159 06.2	10.5	N10 41.6	14.8	59.5
	19	108 43.8	10.0	173 35.7	10.5	10 26.8	14.9	59.5
	20	123 43.7	10.6	188 05.2	10.5	10 11.9	15.0	59.5
	21	138 43.6	·· 11.2	202 34.7	10.6	9 56.9	15.0	59.5
	22	153 43.4	11.8	217 04.3	10.6	9 41.9	15.1	59.5
	23	168 43.3	12.4	231 33.9	10.6	9 26.8	15.2	59.6
	18 00	183 43.2	S19 13.0	246 03.5	10.7	N 9 11.6	15.2	59.6
	01	198 43.0	13.6	260 33.2	10.6	8 56.4	15.3	59.6
	02	213 42.9	14.2	275 02.8	10.7	8 41.1	15.4	59.6
	03	228 42.8	·· 14.8	289 32.5	10.7	8 25.7	15.4	59.7
	04	243 42.6	15.4	304 02.2	10.7	8 10.3	15.4	59.7
	05	258 42.5	16.0	318 31.9	10.7	7 54.9	15.5	59.7
	06	273 42.4	S19 16.6	333 01.6	10.8	N 7 39.4	15.6	59.7
	07	288 42.2	17.2	347 31.4	10.8	7 23.8	15.6	59.7
	08	303 42.1	17.8	2 01.2	10.7	7 08.2	15.7	59.8
S	09	318 42.0	·· 18.3	16 30.9	10.8	6 52.5	15.7	59.8
U	10	333 41.8	18.9	31 00.7	10.8	6 36.8	15.7	59.8
N	11	348 41.7	19.5	45 30.5	10.8	6 21.1	15.8	59.8
D	12	3 41.6	S19 20.1	60 00.3	10.9	N 6 05.3	15.9	59.8
A	13	18 41.4	20.7	74 30.2	10.8	5 49.4	15.9	59.9
Y	14	33 41.3	21.3	89 00.0	10.8	5 33.5	15.9	59.9
	15	48 41.2	·· 21.9	103 29.8	10.9	5 17.6	16.0	59.9
	16	63 41.0	22.5	117 59.7	10.8	5 01.6	16.0	59.9
	17	78 40.9	23.1	132 29.5	10.9	4 45.6	16.0	59.9
	18	93 40.7	S19 23.6	146 59.4	10.8	N 4 29.6	16.1	59.9
	19	108 40.6	24.2	161 29.2	10.9	4 13.5	16.1	60.0
	20	123 40.5	24.8	175 59.1	10.8	3 57.4	16.2	60.0
	21	138 40.3	·· 25.4	190 28.9	10.9	3 41.2	16.2	60.0
	22	153 40.2	26.0	204 58.8	10.8	3 25.0	16.2	60.0
	23	168 40.1	26.6	219 28.6	10.8	3 08.8	16.2	60.0
	19 00	183 39.9	S19 27.2	233 58.4	10.9	N 2 52.6	16.2	60.0
	01	198 39.8	27.7	248 28.3	10.8	2 36.4	16.3	60.1
	02	213 39.6	28.3	262 58.1	10.9	2 20.1	16.3	60.1
	03	228 39.5	·· 28.9	277 28.0	10.8	2 03.8	16.3	60.1
	04	243 39.3	29.5	291 57.8	10.8	1 47.5	16.4	60.1
	05	258 39.2	30.1	306 27.6	10.8	1 31.1	16.3	60.1
	06	273 39.1	S19 30.6	320 57.4	10.8	N 1 14.8	16.4	60.1
	07	288 38.9	31.2	335 27.2	10.8	0 58.4	16.4	60.2
	08	303 38.8	31.8	349 57.0	10.7	0 42.0	16.4	60.2
M	09	318 38.6	·· 32.4	4 26.7	10.8	0 25.6	16.4	60.2
O	10	333 38.5	32.9	18 56.5	10.7	N 0 09.2	16.4	60.2
N	11	348 38.3	33.5	33 26.2	10.7	S 0 07.2	16.5	60.2
D	12	3 38.2	S19 34.1	47 55.9	10.7	S 0 23.7	16.4	60.2
A	13	18 38.1	34.7	62 25.6	10.7	0 40.1	16.4	60.2
Y	14	33 37.9	35.2	76 55.3	10.7	0 56.5	16.5	60.2
	15	48 37.8	·· 35.8	91 25.0	10.6	1 13.0	16.4	60.3
	16	63 37.6	36.4	105 54.6	10.6	1 29.4	16.5	60.3
	17	78 37.5	37.0	120 24.2	10.6	1 45.9	16.4	60.3
	18	93 37.3	S19 37.5	134 53.8	10.6	S 2 02.3	16.4	60.3
	19	108 37.2	38.1	149 23.4	10.5	2 18.7	16.5	60.3
	20	123 37.0	38.7	163 52.9	10.5	2 35.2	16.4	60.3
	21	138 36.9	·· 39.2	178 22.4	10.5	2 51.6	16.4	60.3
	22	153 36.7	39.8	192 51.9	10.5	3 08.0	16.4	60.3
	23	168 36.6	40.4	207 21.4	10.4	3 24.4	16.4	60.3
		S.D. 16.2	d 0.6	S.D. 16.2		16.3		16.4

Lat.	Twilight Naut.	Twilight Civil	Sunrise	Moonrise 17	Moonrise 18	Moonrise 19	Moonrise 20
°	h m	h m	h m	h m	h m	h m	h m
N 72	07 11	08 49	▬	23 36	26 02	02 02	04 25
N 70	06 59	08 24	10 12	23 51	26 05	02 05	04 17
68	06 50	08 04	09 28	24 03	00 03	02 07	04 11
66	06 42	07 49	08 59	24 13	00 13	02 09	04 06
64	06 35	07 36	08 37	24 21	00 21	02 11	04 02
62	06 29	07 25	08 20	24 28	00 28	02 13	03 58
60	06 23	07 16	08 06	24 34	00 34	02 14	03 55
N 58	06 18	07 07	07 54	24 39	00 39	02 15	03 52
56	06 14	07 00	07 43	24 44	00 44	02 16	03 50
54	06 10	06 53	07 34	24 48	00 48	02 17	03 48
52	06 06	06 47	07 25	24 52	00 52	02 18	03 46
50	06 02	06 42	07 18	24 55	00 55	02 19	03 44
45	05 54	06 30	07 02	25 03	01 03	02 21	03 40
N 40	05 47	06 19	06 49	25 09	01 09	02 22	03 37
35	05 40	06 10	06 37	00 05	01 14	02 23	03 34
30	05 33	06 02	06 28	00 12	01 18	02 25	03 31
20	05 21	05 47	06 11	00 26	01 26	02 26	03 27
N 10	05 08	05 34	05 56	00 38	01 33	02 28	03 23
0	04 54	05 20	05 42	00 49	01 40	02 30	03 20
S 10	04 39	05 05	05 27	01 00	01 46	02 31	03 17
20	04 20	04 48	05 12	01 12	01 53	02 33	03 13
30	03 57	04 28	04 54	01 25	02 01	02 35	03 09
35	03 42	04 16	04 44	01 33	02 05	02 36	03 07
40	03 23	04 01	04 32	01 41	02 10	02 38	03 05
45	03 00	03 44	04 18	01 51	02 16	02 39	03 02
S 50	02 28	03 21	04 01	02 04	02 23	02 41	02 58
52	02 11	03 10	03 52	02 09	02 26	02 42	02 57
54	01 50	02 57	03 43	02 15	02 30	02 42	02 55
56	01 23	02 42	03 33	02 22	02 34	02 43	02 53
58	00 38	02 25	03 21	02 30	02 38	02 45	02 51
S 60	////	02 02	03 07	02 39	02 43	02 46	02 49

Lat.	Sunset	Twilight Civil	Twilight Naut.	Moonset 17	Moonset 18	Moonset 19	Moonset 20
°	h m	h m	h m	h m	h m	h m	h m
N 72	▬	14 40	16 19	15 47	15 10	14 38	14 04
N 70	13 18	15 06	16 30	15 30	15 03	14 39	14 15
68	14 02	15 25	16 40	15 15	14 57	14 41	14 24
66	14 30	15 41	16 48	15 04	14 52	14 42	14 31
64	14 52	15 54	16 55	14 54	14 48	14 43	14 37
62	15 10	16 05	17 01	14 45	14 45	14 44	14 43
60	15 24	16 14	17 06	14 38	14 42	14 45	14 48
N 58	15 36	16 22	17 11	14 32	14 39	14 45	14 52
56	15 47	16 30	17 16	14 26	14 36	14 46	14 56
54	15 56	16 36	17 20	14 21	14 34	14 46	14 59
52	16 05	16 43	17 24	14 16	14 32	14 47	15 02
50	16 12	16 48	17 28	14 12	14 30	14 47	15 05
45	16 28	17 00	17 36	14 02	14 26	14 48	15 12
N 40	16 41	17 11	17 44	13 54	14 22	14 49	15 17
35	16 53	17 20	17 50	13 48	14 19	14 50	15 21
30	17 03	17 28	17 57	13 42	14 17	14 51	15 25
20	17 20	17 43	18 10	13 31	14 12	14 52	15 32
N 10	17 35	17 57	18 23	13 22	14 08	14 53	15 39
0	17 49	18 11	18 36	13 13	14 03	14 53	15 44
S 10	18 03	18 26	18 52	13 04	13 59	14 54	15 50
20	18 19	18 42	19 10	12 55	13 55	14 55	15 56
30	18 36	19 03	19 34	12 44	13 50	14 56	16 04
35	18 47	19 15	19 50	12 38	13 47	14 57	16 08
40	18 59	19 30	20 08	12 30	13 44	14 57	16 12
45	19 13	19 48	20 32	12 22	13 40	14 58	16 18
S 50	19 31	20 11	21 04	12 11	13 35	14 59	16 24
52	19 39	20 22	21 22	12 07	13 33	14 59	16 27
54	19 48	20 35	21 43	12 01	13 30	15 00	16 31
56	19 59	20 50	22 12	11 55	13 28	15 00	16 35
58	20 11	21 08	23 01	11 49	13 25	15 01	16 39
S 60	20 25	21 31	////	11 41	13 21	15 02	16 43

Day	SUN Eqn. of Time 00ʰ	SUN Eqn. of Time 12ʰ	SUN Mer. Pass.	MOON Mer. Pass. Upper	MOON Mer. Pass. Lower	Age	Phase
	m s	m s	h m	h m	h m	d	
17	15 05	14 59	11 45	07 01	19 27	24	
18	14 53	14 47	11 45	07 52	20 17	25	◐
19	14 40	14 33	11 45	08 42	21 07	26	

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Figure 9-1. *Nautical Almanac* right-hand daily pages.

Azimuth of the Sun, Continued

42m INCREMENTS AND CORRECTIONS 43m

42m s	SUN PLANETS ° ′	ARIES ° ′	MOON ° ′	v or d ′	Corrn ′	v or d ′	Corrn ′	v or d ′	Corrn ′
00	10 30·0	10 31·7	10 01·3	0·0	0·0	6·0	4·3	12·0	8·5
01	10 30·3	10 32·0	10 01·5	0·1	0·1	6·1	4·3	12·1	8·6
02	10 30·5	10 32·2	10 01·8	0·2	0·1	6·2	4·4	12·2	8·6
03	10 30·8	10 32·5	10 02·0	0·3	0·2	6·3	4·5	12·3	8·7
04	10 31·0	10 32·7	10 02·3	0·4	0·3	6·4	4·5	12·4	8·8
05	10 31·3	10 33·0	10 02·5	0·5	0·4	6·5	4·6	12·5	8·9
06	10 31·5	10 33·2	10 02·7	0·6	0·4	6·6	4·7	12·6	8·9
07	10 31·8	10 33·5	10 03·0	0·7	0·5	6·7	4·7	12·7	9·0
08	10 32·0	10 33·7	10 03·2	0·8	0·6	6·8	4·8	12·8	9·1
09	10 32·3	10 34·0	10 03·4	0·9	0·6	6·9	4·9	12·9	9·1
10	10 32·5	10 34·2	10 03·7	1·0	0·7	7·0	5·0	13·0	9·2
11	10 32·8	10 34·5	10 03·9	1·1	0·8	7·1	5·0	13·1	9·3
12	10 33·0	10 34·7	10 04·2	1·2	0·9	7·2	5·1	13·2	9·4
13	10 33·3	10 35·0	10 04·4	1·3	0·9	7·3	5·2	13·3	9·4
14	10 33·5	10 35·2	10 04·6	1·4	1·0	7·4	5·2	13·4	9·5
15	10 33·8	10 35·5	10 04·9	1·5	1·1	7·5	5·3	13·5	9·6
16	10 34·0	10 35·7	10 05·1	1·6	1·1	7·6	5·4	13·6	9·6
17	10 34·3	10 36·0	10 05·4	1·7	1·2	7·7	5·5	13·7	9·7
18	10 34·5	10 36·2	10 05·6	1·8	1·3	7·8	5·5	13·8	9·8
19	10 34·8	10 36·5	10 05·8	1·9	1·3	7·9	5·6	13·9	9·8
20	10 35·0	10 36·7	10 06·1	2·0	1·4	8·0	5·7	14·0	9·9
21	18 35·3	10 37·0	10 06·3	2·1	1·5	8·1	5·7	14·1	10·0
22	10 35·5	10 37·2	10 06·5	2·2	1·6	8·2	5·8	14·2	10·1
23	10 35·8	10 37·5	10 06·8	2·3	1·6	8·3	5·9	14·3	10·1
24	10 36·0	10 37·7	10 07·0	2·4	1·7	8·4	6·0	14·4	10·2
25	10 36·3	10 38·0	10 07·3	2·5	1·8	8·5	6·0	14·5	10·3
26	10 36·5	10 38·2	10 07·5	2·6	1·8	8·6	6·1	14·6	10·3
27	10 36·8	10 38·5	10 07·7	2·7	1·9	8·7	6·2	14·7	10·4
28	10 37·0	10 38·7	10 08·0	2·8	2·0	8·8	6·2	14·8	10·5
29	10 37·3	10 39·0	10 08·2	2·9	2·1	8·9	6·3	14·9	10·6
30	10 37·5	10 39·2	10 08·5	3·0	2·1	9·0	6·4	15·0	10·6
31	10 37·8	10 39·5	10 08·7	3·1	2·2	9·1	6·4	15·1	10·7
32	10 38·0	10 39·7	10 08·9	3·2	2·3	9·2	6·5	15·2	10·8
33	10 38·3	10 40·0	10 09·2	3·3	2·3	9·3	6·6	15·3	10·8
34	10 38·5	10 40·2	10 09·4	3·4	2·4	9·4	6·7	15·4	10·9
35	10 38·8	10 40·5	10 09·7	3·5	2·5	9·5	6·7	15·5	11·0
36	10 39·0	10 40·7	10 09·9	3·6	2·6	9·6	6·8	15·6	11·1
37	10 39·3	10 41·0	10 10·1	3·7	2·6	9·7	6·9	15·7	11·1
38	10 39·5	10 41·3	10 10·4	3·8	2·7	9·8	6·9	15·8	11·2
39	10 39·8	10 41·5	10 10·6	3·9	2·8	9·9	7·0	15·9	11·3
40	10 40·0	10 41·8	10 10·8	4·0	2·8	10·0	7·1	16·0	11·3
41	10 40·3	10 42·0	10 11·1	4·1	2·9	10·1	7·2	16·1	11·4
42	10 40·5	10 42·3	10 11·3	4·2	3·0	10·2	7·2	16·2	11·5
43	10 40·8	10 42·5	10 11·6	4·3	3·0	10·3	7·3	16·3	11·5
44	10 41·0	10 42·8	10 11·8	4·4	3·1	10·4	7·4	16·4	11·6
45	10 41·3	10 43·0	10 12·0	4·5	3·2	10·5	7·4	16·5	11·7
46	10 41·5	10 43·3	10 12·3	4·6	3·3	10·6	7·5	16·6	11·8
47	10 41·8	10 43·5	10 12·5	4·7	3·3	10·7	7·6	16·7	11·8
48	10 42·0	10 43·8	10 12·8	4·8	3·4	10·8	7·7	16·8	11·9
49	10 42·3	10 44·0	10 13·0	4·9	3·5	10·9	7·7	16·9	12·0
50	10 42·5	10 44·3	10 13·2	5·0	3·5	11·0	7·8	17·0	12·0
51	10 42·8	10 44·5	10 13·5	5·1	3·6	11·1	7·9	17·1	12·1
52	10 43·0	10 44·8	10 13·7	5·2	3·7	11·2	7·9	17·2	12·2
53	10 43·3	10 45·0	10 13·9	5·3	3·8	11·3	8·0	17·3	12·3
54	10 43·5	10 45·3	10 14·2	5·4	3·8	11·4	8·1	17·4	12·3
55	10 43·8	10 45·5	10 14·4	5·5	3·9	11·5	8·1	17·5	12·4
56	10 44·0	10 45·8	10 14·7	5·6	4·0	11·6	8·2	17·6	12·5
57	10 44·3	10 46·0	10 14·9	5·7	4·0	11·7	8·3	17·7	12·5
58	10 44·5	10 46·3	10 15·1	5·8	4·1	11·8	8·4	17·8	12·6
59	10 44·8	10 46·5	10 15·4	5·9	4·2	11·9	8·4	17·9	12·7
60	10 45·0	10 46·8	10 15·6	6·0	4·3	12·0	8·5	18·0	12·8

43m s	SUN PLANETS ° ′	ARIES ° ′	MOON ° ′	v or d ′	Corrn ′	v or d ′	Corrn ′	v or d ′	Corrn ′
00	10 45·0	10 46·8	10 15·6	0·0	0·0	6·0	4·4	12·0	8·7
01	10 45·3	10 47·0	10 15·9	0·1	0·1	6·1	4·4	12·1	8·8
02	10 45·5	10 47·3	10 16·1	0·2	0·1	6·2	4·5	12·2	8·8
03	10 45·8	10 47·5	10 16·3	0·3	0·2	6·3	4·6	12·3	8·9
04	10 46·0	10 47·8	10 16·6	0·4	0·3	6·4	4·6	12·4	9·0
05	10 46·3	10 48·0	10 16·8	0·5	0·4	6·5	4·7	12·5	9·1
06	10 46·5	10 48·3	10 17·0	0·6	0·4	6·6	4·8	12·6	9·1
07	10 46·8	10 48·5	10 17·3	0·7	0·5	6·7	4·9	12·7	9·2
08	10 47·0	10 48·8	10 17·5	0·8	0·6	6·8	4·9	12·8	9·3
09	10 47·3	10 49·0	10 17·8	0·9	0·7	6·9	5·0	12·9	9·4
10	10 47·5	10 49·3	10 18·0	1·0	0·7	7·0	5·1	13·0	9·4
11	10 47·8	10 49·5	10 18·2	1·1	0·8	7·1	5·1	13·1	9·5
12	10 48·0	10 49·8	10 18·5	1·2	0·9	7·2	5·2	13·2	9·6
13	10 48·3	10 50·0	10 18·7	1·3	0·9	7·3	5·3	13·3	9·6
14	10 48·5	10 50·3	10 19·0	1·4	1·0	7·4	5·4	13·4	9·7
15	10 48·8	10 50·5	10 19·2	1·5	1·1	7·5	5·4	13·5	9·8
16	10 49·0	10 50·8	10 19·4	1·6	1·2	7·6	5·5	13·6	9·9
17	10 49·3	10 51·0	10 19·7	1·7	1·2	7·7	5·6	13·7	9·9
18	10 49·5	10 51·3	10 19·9	1·8	1·3	7·8	5·7	13·8	10·0
19	10 49·8	10 51·5	10 20·2	1·9	1·4	7·9	5·7	13·9	10·1
20	10 50·0	10 51·8	10 20·4	2·0	1·5	8·0	5·8	14·0	10·2
21	10 50·3	10 52·0	10 20·6	2·1	1·5	8·1	5·9	14·1	10·2
22	10 50·5	10 52·3	10 20·9	2·2	1·6	8·2	5·9	14·2	10·3
23	10 50·8	10 52·5	10 21·1	2·3	1·7	8·3	6·0	14·3	10·4
24	10 51·0	10 52·8	10 21·3	2·4	1·7	8·4	6·1	14·4	10·4
25	10 51·3	10 53·0	10 21·6	2·5	1·8	8·5	6·2	14·5	10·5
26	10 51·5	10 53·3	10 21·8	2·6	1·9	8·6	6·2	14·6	10·6
27	10 51·8	10 53·5	10 22·1	2·7	2·0	8·7	6·3	14·7	10·7
28	10 52·0	10 53·8	10 22·3	2·8	2·0	8·8	6·4	14·8	10·7
29	10 52·3	10 54·0	10 22·5	2·9	2·1	8·9	6·5	14·9	10·8
30	10 52·5	10 54·3	10 22·8	3·0	2·2	9·0	6·5	15·0	10·9
31	10 52·8	10 54·5	10 23·0	3·1	2·2	9·1	6·6	15·1	10·9
32	10 53·0	10 54·8	10 23·3	3·2	2·3	9·2	6·7	15·2	11·0
33	10 53·3	10 55·0	10 23·5	3·3	2·4	9·3	6·7	15·3	11·1
34	10 53·5	10 55·3	10 23·7	3·4	2·5	9·4	6·8	15·4	11·2
35	10 53·8	10 55·5	10 24·0	3·5	2·5	9·5	6·9	15·5	11·2
36	10 54·0	10 55·8	10 24·2	3·6	2·6	9·6	7·0	15·6	11·3
37	10 54·3	10 56·0	10 24·4	3·7	2·7	9·7	7·0	15·7	11·4
38	10 54·5	10 56·3	10 24·7	3·8	2·8	9·8	7·1	15·8	11·5
39	10 54·8	10 56·5	10 24·9	3·9	2·8	9·9	7·2	15·9	11·5
40	10 55·0	10 56·8	10 25·2	4·0	2·9	10·0	7·3	16·0	11·6
41	10 55·3	10 57·0	10 25·4	4·1	3·0	10·1	7·3	16·1	11·7
42	10 55·5	10 57·3	10 25·6	4·2	3·0	10·2	7·4	16·2	11·7
43	10 55·8	10 57·5	10 25·9	4·3	3·1	10·3	7·5	16·3	11·8
44	10 56·0	10 57·8	10 26·1	4·4	3·2	10·4	7·5	16·4	11·9
45	10 56·3	10 58·0	10 26·4	4·5	3·3	10·5	7·6	16·5	12·0
46	10 56·5	10 58·3	10 26·6	4·6	3·3	10·6	7·7	16·6	12·0
47	10 56·8	10 58·5	10 26·8	4·7	3·4	10·7	7·8	16·7	12·1
48	10 57·0	10 58·8	10 27·1	4·8	3·5	10·8	7·8	16·8	12·2
49	10 57·3	10 59·0	10 27·3	4·9	3·6	10·9	7·9	16·9	12·3
50	10 57·5	10 59·3	10 27·5	5·0	3·6	11·0	8·0	17·0	12·3
51	10 57·8	10 59·6	10 27·8	5·1	3·7	11·1	8·0	17·1	12·4
52	10 58·0	10 59·8	10 28·0	5·2	3·8	11·2	8·1	17·2	12·5
53	10 58·3	11 00·1	10 28·3	5·3	3·8	11·3	8·2	17·3	12·5
54	10 58·5	11 00·3	10 28·5	5·4	3·9	11·4	8·3	17·4	12·6
55	10 58·8	11 00·6	10 28·7	5·5	4·0	11·5	8·3	17·5	12·7
56	10 59·0	11 00·8	10 29·0	5·6	4·1	11·6	8·4	17·6	12·8
57	10 59·3	11 01·1	10 29·2	5·7	4·1	11·7	8·5	17·7	12·8
58	10 59·5	11 01·3	10 29·5	5·8	4·2	11·8	8·6	17·8	12·9
59	10 59·8	11 01·6	10 29·7	5·9	4·3	11·9	8·6	17·9	13·0
60	11 00·0	11 01·8	10 29·9	6·0	4·4	12·0	8·7	18·0	13·1

26NVM033

Figure 9-2. *Nautical Almanac* Increments and Corrections page.

Look at the left-hand column of the stip form below. Notice that you'll find values for Dec. Inc/Z Diff, Lat Inc/Z Diff, and LHA Inc/Z Diff. This is where we enter the leftover values from our whole degrees of DR Lat, Declination, and LHA. To do this, we must convert our leftover values into tenths of degrees by dividing each by 60 and rounding to the closest tenth of a degree. Finding Z Diff is a matter of inspecting Pub 229 (see figs. 9-3 and 9-4) in the following manner:

For Dec Inc/Z Diff note the values for the whole degree of dec that you entered the table with and the next high dec, then find the difference. Here are the values for our example problem: Dec 19° Z = 129.1 Dec 20° Z = 129.8. The difference between the values is 0.7. Since the value is increasing between 19° and 20°, we assign it a positive value (+).

Repeat the same procedure for finding Z Diff for Latitude and LHA. In other words, compare lat. 33° and lat 34°. Then compare LHA 51° and 52°.

OPNAV 3130/ Azimuth by 229	**ACTION**	**Completed Strip Form**
Tab Z	Enter Pub 229 with entering arguments of Lat 33°, LHA 51°, and Dee 19°. Make sure that you enter on the portion of the page that indicates **LATITUDE CONTRARY TO DECLINATION.** Follow 19° of Dee across the page to where it falls under the 33° Latitude column and record the value for Tab Z.	129.1
Dec Inc/Z Diff	Dec. Inc (left) = 31.6' + 60 which = .53 rounded to 0.5. Compares Z's for Z Diff.	0.5 / + 0.7
Dec Corr	Multiply Dee Inc by Z Diff.	+ 0.35
Lat Inc/Z Diff	Lat Inc (left) = 37.0' + 60 which = .62 rounded to 0.6. Compares Z's for Z Diff.	0.6 / + 0.3
Lat Corr	Multiply Lat Inc by Z Diff.	+ 0.18
LHA Inc/Z Diff	LHA Inc (left) = 53.4' + 60 which = .89 rounded to 0.9. Compares Z's for Z Diff.	0.9 / - 0.7
LHA Corr	Multiply LHA Inc by 2 Diff.	- 0.63
Dec Corr	Drop the Dec Corr Down.	+ 0.35
Lat Corr	Drop the Lat Corr Down.	+ 0.18
Total corr	Add the LHA, Dec, and Lat Corr.	- 0.10

We have now accounted for our leftover values and now can find the Exact Z.

LATITUDE CONTRARY NAME TO DECLINATION — L.H.A. 51°, 309°

Dec.	30° Hc	30° d	30° Z	31° Hc	31° d	31° Z	32° Hc	32° d	32° Z	33° Hc	33° d	33° Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	33 01.5	-36.0	112.0	32 38.7	36.9	112.6	32 15.3	37.8	113.2	31 51.4	-38.7	113.8	0
1	32 25.5	36.4	113.0	32 01.8	37.3	113.6	31 37.5	38.2	114.1	31 12.7	39.0	114.7	1
2	31 49.1	36.8	113.9	31 24.5	37.7	114.5	30 59.3	38.5	115.0	30 33.7	39.4	115.6	2
3	31 12.3	37.3	114.9	30 46.8	38.1	115.4	30 20.8	38.9	115.9	29 54.3	39.7	116.5	3
4	30 35.0	37.6	115.8	30 08.7	38.4	116.3	29 41.9	39.3	116.8	29 14.6	40.1	117.3	4
5	29 57.4	-37.9	116.7	29 30.3	38.8	117.2	29 02.6	39.6	117.7	28 34.5	-40.3	118.2	5
6	29 19.5	38.3	117.6	28 51.5	39.1	118.1	28 23.0	39.9	118.5	27 54.2	40.7	119.0	6
7	28 41.2	38.7	118.4	28 12.4	39.5	118.9	27 43.1	40.2	119.4	27 13.5	41.0	119.8	7
8	28 02.5	39.0	119.3	27 32.9	39.7	119.8	27 02.9	40.5	120.2	26 32.5	41.2	120.7	8
9	27 23.5	39.3	120.2	26 53.2	40.1	120.6	26 22.4	40.8	121.0	25 51.3	41.5	121.5	9
10	26 44.2	-39.5	121.0	26 13.1	40.3	121.4	25 41.6	41.0	121.9	25 09.8	-41.8	122.3	10
11	26 04.7	39.9	121.9	25 32.8	40.6	122.3	25 00.6	41.3	122.7	24 28.0	42.0	123.1	11
12	25 24.8	40.2	122.7	24 52.2	40.9	123.1	24 19.3	41.6	123.5	23 46.0	42.2	123.8	12
13	24 44.6	40.4	123.5	24 11.3	41.1	123.9	23 37.7	41.8	124.3	23 03.8	42.5	124.6	13
14	24 04.2	40.7	124.3	23 30.2	41.3	124.7	22 55.9	42.0	125.0	22 21.3	42.6	125.4	14
15	23 23.5	-40.9	125.1	22 48.9	41.6	125.5	22 13.9	42.2	125.8	21 38.7	42.9	126.1	15
16	22 42.6	41.1	125.9	22 07.3	41.8	126.3	21 31.7	42.5	126.6	20 55.8	43.1	126.9	16
17	22 01.5	41.4	126.7	21 25.5	42.0	127.0	20 49.2	42.6	127.3	20 12.7	43.2	127.6	17
18	21 20.1	41.6	127.5	20 43.5	42.2	127.8	20 06.6	42.8	128.1	19 29.5	43.5	128.4	18
19	20 38.5	41.8	128.3	20 01.3	42.5	128.5	19 23.8	43.1	128.8	18 46.0	43.6	129.1	19
20	19 56.7	-41.9	129.0	19 18.8	42.5	129.3	18 40.7	43.1	129.6	18 02.4	43.7	129.8	20
21	19 14.8	42.2	129.8	18 36.3	42.8	130.0	17 57.6	43.4	130.3	17 18.7	44.0	130.5	21
22	18 32.6	42.4	130.5	17 53.5	42.9	130.8	17 14.2	43.5	131.0	16 34.7	44.0	131.3	22
23	17 50.2	42.5	131.3	17 10.6	43.1	131.5	16 30.7	43.6	131.7	15 50.7	44.2	132.0	23
36	8 27.3	44.0	140.5	7 40.9	44.4	140.6	6 54.5	44.9	140.7	6 08.1	45.4	140.8	36
37	7 43.3	44.1	141.2	6 56.5	44.5	141.3	6 09.6	44.9	141.4	5 22.7	45.3	141.4	37
38	6 59.2	44.1	141.9	6 12.0	44.6	142.0	5 24.7	45.0	142.0	4 37.4	45.5	142.1	38
39	6 15.1	44.2	142.6	5 27.4	44.6	142.6	4 39.7	45.0	142.7	3 51.9	45.4	142.7	39
40	5 30.9	-44.2	143.3	4 42.8	44.6	143.3	3 54.7	45.1	143.4	3 06.5	45.5	143.4	40
41	4 46.7	44.3	143.9	3 58.2	44.7	144.0	3 09.6	45.1	144.0	2 21.0	45.4	144.1	41
42	4 02.4	44.3	144.6	3 13.5	44.7	144.7	2 24.5	45.1	144.7	1 35.6	45.5	144.7	42
43	3 18.1	44.3	145.3	2 28.8	44.8	145.3	1 39.4	45.1	145.3	0 50.1	45.5	145.4	43
44	2 33.8	44.4	146.0	1 44.0	44.7	146.0	0 54.3	45.1	146.0	0 04.6	45.6	146.0	44
45	1 49.4	44.3	146.6	0 59.3	44.7	146.7	0 09.2	45.1	146.7	0 41.0	45.5	33.3	45
46	1 05.1	44.4	147.3	0 14.6	44.8	147.3	0 35.9	45.2	32.7	1 26.5	45.4	32.7	46
47	0 20.7	44.4	148.0	0 30.2	44.7	32.0	1 21.1	45.1	32.0	2 11.9	45.5	32.0	47
48	0 23.7	44.4	31.3	1 14.9	44.8	31.3	2 06.2	45.1	31.4	2 57.4	45.5	31.4	48
49	1 08.1	44.3	30.7	1 59.7	44.7	30.7	2 51.3	45.0	30.7	3 42.9	45.4	30.7	49
50	1 52.4	44.4	30.0	2 44.4	44.7	30.0	3 36.3	45.1	30.0	4 28.3	45.4	30.1	50
51	2 36.8	44.3	29.3	3 29.1	44.7	29.3	4 21.4	45.0	29.4	5 13.7	45.3	29.4	51
52	3 21.1	44.3	28.6	4 13.8	44.6	28.7	5 06.4	45.0	28.7	5 59.0	45.3	28.8	52
53	4 05.4	44.3	28.0	4 58.4	44.6	28.0	5 51.4	44.9	28.0	6 44.3	45.2	28.1	53
81	24 07.0	40.4	7.7	25 06.4	40.5	7.7	26 05.9	40.6	7.8	27 05.3	40.7	7.8	81
82	24 47.4	40.1	6.8	25 46.9	40.3	6.9	26 46.5	40.3	7.0	27 46.0	40.5	7.0	82
83	25 27.5	39.9	6.0	26 27.2	39.9	6.1	27 26.8	40.1	6.1	28 26.5	40.1	6.2	83
84	26 07.4	39.5	5.2	27 07.1	39.6	5.2	28 06.9	39.7	5.3	29 06.6	39.8	5.3	84
85	26 46.9	-39.3	4.4	27 46.7	39.4	4.4	28 46.6	39.4	4.4	29 46.4	39.4	4.5	85
86	27 26.2	38.9	3.5	28 26.1	39.0	3.5	29 26.0	39.0	3.6	30 25.8	39.1	3.6	86
87	28 05.1	38.7	2.6	29 05.1	38.6	2.7	30 05.0	38.7	2.7	31 04.9	38.8	2.7	87
88	28 43.8	38.3	1.8	29 43.7	38.4	1.8	30 43.7	38.3	1.8	31 43.7	38.3	1.8	88
89	29 22.1	37.9	0.9	30 22.1	37.9	0.9	31 22.0	38.0	0.9	32 22.0	38.0	0.9	89
90	30 00.0	-37.6	0.0	31 00.0	-37.6	0.0	32 00.0	-37.6	0.0	33 00.0	-37.6	0.0	90
	30°			31°			32°			33°			

Dec.	34° Hc	34° d	34° Z	35° Hc	35° d	35° Z	36° Hc	36° d	36° Z	37° Hc	37° d	37° Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	31 26.9	39.5	114.4	31 01.9	40.3	114.9	30 36.4	41.2	115.5	30 10.3	41.9	116.0	0
1	30 47.4	39.9	115.2	30 21.6	40.7	115.8	29 55.2	41.4	116.3	29 28.4	42.2	116.8	1
2	30 07.5	40.2	116.1	29 40.9	41.0	116.6	29 13.8	41.8	117.1	28 46.2	42.5	117.6	2
3	29 27.3	40.5	117.0	28 59.9	41.3	117.5	28 32.0	42.0	117.9	28 03.7	42.8	118.4	3
4	28 46.8	40.8	117.8	28 18.6	41.6	118.3	27 50.0	42.4	118.8	27 20.9	43.1	119.2	4
5	28 06.0	41.1	118.6	27 37.0	41.9	119.1	27 07.6	42.6	119.6	26 37.8	43.3	120.0	5
6	27 24.9	41.5	119.5	26 55.1	42.1	119.9	26 25.0	42.8	120.3	25 54.5	43.5	120.8	6
7	26 43.4	41.7	120.3	26 13.0	42.4	120.7	25 42.2	43.1	121.1	25 11.0	43.8	121.5	7
8	26 01.7	41.9	121.1	25 30.6	42.7	121.5	24 59.1	43.4	121.9	24 27.2	44.0	122.3	8
9	25 19.8	42.2	121.9	24 47.9	42.9	122.3	24 15.7	43.5	122.7	23 43.2	44.2	123.0	9
10	24 37.6	42.5	122.7	24 05.0	43.1	123.0	23 32.2	43.8	123.4	22 59.0	44.4	123.8	10
11	23 55.1	42.6	123.4	23 21.9	43.3	123.8	22 48.4	44.0	124.2	22 14.6	44.6	124.5	11
12	23 12.5	42.9	124.2	22 38.6	43.6	124.5	22 04.4	44.2	124.9	21 30.0	44.8	125.2	12
13	22 29.6	43.1	125.0	21 55.0	43.7	125.3	21 20.2	44.3	125.6	20 45.2	45.0	125.9	13
14	21 46.5	43.4	125.7	21 11.3	43.9	126.0	20 35.9	44.6	126.3	20 00.2	45.1	126.6	14
15	21 03.1	43.5	126.5	20 27.4	44.1	126.8	19 51.3	44.7	127.0	19 15.1	45.3	127.3	15
16	20 19.6	43.6	127.2	19 43.3	44.3	127.5	19 06.6	44.8	127.8	18 29.8	45.5	128.0	16
17	19 36.0	43.9	127.9	18 59.0	44.5	128.2	18 21.8	45.1	128.5	17 44.3	45.5	128.7	17
18	18 52.1	44.0	128.6	18 14.5	44.6	128.9	17 36.7	45.1	129.2	16 58.8	45.8	129.4	18
19	18 08.1	44.2	129.4	17 29.9	44.7	129.6	16 51.6	45.3	129.8	16 13.0	45.8	130.1	19
20	17 23.9	44.3	130.1	16 45.2	44.9	130.3	16 06.3	45.5	130.5	15 27.2	46.0	130.7	20
21	16 39.6	44.5	130.8	16 00.3	45.0	131.0	15 20.8	45.5	131.2	14 41.2	46.0	131.4	21
22	15 55.1	44.6	131.5	15 15.3	45.2	131.7	14 35.3	45.7	131.9	13 55.2	46.2	132.1	22
23	15 10.5	44.8	132.2	14 30.1	45.2	132.4	13 49.6	45.8	132.5	13 09.0	46.3	132.7	23
36	5 21.6	45.8	140.8	4 35.0	46.2	140.9	3 48.4	46.6	140.9	3 01.8	47.0	141.0	36
37	4 35.8	45.8	141.5	3 48.8	46.2	141.5	3 01.8	46.6	141.6	2 14.8	47.0	141.6	37
38	3 50.0	45.8	142.1	3 02.6	46.2	142.2	2 15.2	46.6	142.2	1 27.8	47.0	142.2	38
39	3 04.2	45.9	142.8	2 16.4	46.3	142.8	1 28.6	46.7	142.8	0 40.8	47.1	142.8	39
40	2 18.3	45.8	143.4	1 30.1	46.2	143.4	0 41.9	46.6	143.5	0 06.3	47.0	36.5	40
41	1 32.5	45.9	144.1	0 43.9	46.3	144.1	0 04.7	46.7	35.9	0 53.3	47.1	35.9	41
42	0 46.6	45.9	144.7	0 02.4	46.3	35.3	0 51.4	46.6	35.3	1 40.4	47.0	35.3	42
43	0 00.7	45.9	145.4	0 48.7	46.2	34.6	1 38.0	46.7	34.7	2 27.4	47.0	34.7	43
44	0 45.2	45.9	34.0	1 34.9	46.3	34.0	2 24.7	46.6	34.0	3 14.4	47.0	34.1	44
45	1 31.1	45.8	33.3	2 21.2	46.2	33.4	3 11.3	46.6	33.4	4 01.4	46.9	33.4	45
46	2 16.9	45.9	32.7	3 07.4	46.2	32.7	3 57.9	46.6	32.8	4 48.3	47.0	32.8	46
47	3 02.8	45.8	32.1	3 53.6	46.2	32.1	4 44.5	46.5	32.1	5 35.3	46.8	32.2	47
48	3 48.6	45.8	31.4	4 39.8	46.2	31.4	5 31.0	46.5	31.5	6 22.1	46.9	31.5	48
49	4 34.4	45.8	30.8	5 26.0	46	30.8	6 17.5	46.4	30.9	7 09.0	46.8	30.9	49
50	5 20.2	45.7	30.1	6 12.1	46.0	30.2	7 03.9	46.4	30.2	7 55.8	46.7	30.3	50
51	6 05.9	45.7	29.5	6 58.1	46.0	29.5	7 50.3	46.4	29.6	8 42.5	46.7	29.7	51
52	6 51.6	45.6	28.8	7 44.1	46.0	28.9	8 36.7	46.2	28.9	9 29.2	46.6	29.0	52
53	7 37.2	45.6	28.2	8 30.1	45.9	28.2	9 22.9	46.2	28.3	10 15.8	46.5	28.4	53
81	28 04.8	40.8	7.9	29 04.2	40.9	8.0	30 03.6	41.1	8.1	31 03.0	41.2	8.2	81
82	28 45.6	40.5	7.1	29 45.1	40.7	7.2	30 44.7	40.7	7.2	31 44.2	40.8	7.3	82
83	29 26.1	40.2	6.2	30 25.8	40.3	6.3	31 25.4	40.4	6.4	32 25.0	40.5	6.4	83
84	30 06.3	39.9	5.4	31 06.1	39.9	5.4	32 05.8	40.0	5.5	33 05.5	40.1	5.6	84
85	30 46.2	39.5	4.5	31 46.0	39.6	4.6	32 45.8	39.7	4.6	33 45.6	39.7	4.7	85
86	31 25.7	39.2	3.6	32 25.6	39.2	3.7	33 25.5	39.2	3.7	34 25.3	39.4	3.8	86
87	32 04.9	38.7	2.8	33 04.8	38.8	2.8	34 04.7	38.9	2.8	35 04.7	38.9	2.8	87
88	32 43.6	38.4	1.8	33 43.6	38.4	1.9	34 43.6	38.4	1.9	35 43.6	38.4	1.9	88
89	33 22.0	38.0	0.9	34 22.0	38.0	0.9	35 22.0	38.0	1.0	36 22.0	38.0	1.0	89
90	34 00.0	-37.5	0.0	35 00.0	-37.5	0.0	36 00.0	-37.5	0.0	37 00.0	-37.5	0.0	90
	34°			35°			36°			37°			

S. Lat. {LHA greater than 180° ... Zn=180°−Z; LHA less than 180° ... Zn=180°+Z}

LATITUDE SAME NAME AS DECLINATION — L.H.A. 129°, 231

26NVM034

Figure 9-3. Pub 229 sample page.

LATITUDE CONTRARY NAME TO DECLINATION **L.H.A. 52°, 308°**

Dec.	30° Hc	30° d	30° Z	31° Hc	31° d	31° Z	32° Hc	32° d	32° Z	33° Hc	33° d	33° Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	32 13.2	35.6	111.3	31 51.1	36.6	111.9	31 28.4	37.4	112.5	31 05.2	38.3	113.1	0
1	31 37.6	36.1	112.3	31 14.5	37.0	112.8	30 51.0	37.9	113.4	30 26.9	38.7	113.9	1
2	31 01.5	36.5	113.2	30 37.5	37.3	113.8	30 13.1	38.2	114.3	29 48.2	39.1	114.8	2
3	30 25.0	36.9	114.1	30 00.2	37.7	114.7	29 34.9	38.6	115.2	29 09.1	39.4	115.7	3
4	29 48.1	37.2	115.1	29 22.5	38.1	115.6	28 56.3	38.9	116.1	28 29.7	39.7	116.6	4
5	29 10.9	37.6	116.0	28 44.4	38.5	116.5	28 17.4	39.2	116.9	27 50.0	40.0	117.4	5
6	28 33.3	38.0	116.8	28 05.9	38.7	117.3	27 38.2	39.6	117.8	27 10.0	40.3	118.3	6
7	27 55.3	38.3	117.7	27 27.2	39.1	118.2	26 58.6	39.8	118.6	26 29.7	40.6	119.1	7
8	27 17.0	38.5	118.6	26 48.1	39.3	119.0	26 18.8	40.1	119.5	25 49.1	40.9	119.9	8
9	26 38.5	38.9	119.5	26 08.8	39.7	119.9	25 38.7	40.4	120.3	25 08.2	41.1	120.7	9
10	25 59.6	39.2	120.3	25 29.1	40.0	120.7	24 58.3	40.7	121.1	24 27.1	41.4	121.5	10
11	25 20.4	39.5	121.1	24 49.1	40.2	121.5	24 17.6	40.9	121.9	23 45.7	41.6	122.3	11
12	24 40.9	39.8	122.0	24 08.9	40.4	122.4	23 36.7	41.2	122.7	23 04.1	41.9	123.1	12
13	24 01.1	40.0	122.8	23 28.5	40.7	123.2	22 55.5	41.4	123.5	22 22.2	42.1	123.9	13
14	23 21.1	40.2	123.6	22 47.8	41.0	124.0	22 14.1	41.6	124.3	21 40.1	42.3	124.6	14
15	22 40.9	40.5	124.4	22 06.8	41.2	124.8	21 32.5	41.9	125.1	20 57.8	42.5	125.4	15
16	22 00.4	40.8	125.2	21 25.6	41.4	125.5	20 50.6	42.0	125.9	20 15.3	42.6	126.2	16
17	21 19.6	40.9	126.0	20 44.2	41.6	126.3	20 08.6	42.3	126.6	19 32.7	42.9	126.9	17
18	20 38.7	41.2	126.8	20 02.6	41.8	127.1	19 26.3	42.4	127.4	18 49.8	43.0	127.6	18
19	19 57.5	41.3	127.6	19 20.8	41.9	127.8	18 43.9	42.6	128.1	18 06.8	43.2	128.4	19
20	19 16.2	41.6	128.3	18 38.9	42.2	128.6	18 01.3	42.8	128.9	17 23.6	43.4	129.1	20
21	18 34.6	41.7	129.1	17 56.7	42.3	129.3	17 18.5	42.9	129.6	16 40.2	43.5	129.8	21
22	17 52.9	41.9	129.9	17 14.4	42.5	130.1	16 35.6	43.1	130.3	15 56.7	43.7	130.5	22
23	17 11.0	42.1	130.6	16 31.9	42.7	130.8	15 52.5	43.2	131.1	15 13.0	43.7	131.3	23
24	16 28.9			15 49.2		131.6							24
36	7 54.0	43.5	139.9	7 08.1	44.0	140.0	6 22.1	44.4	140.1	5 36.0	44.8	140.2	36
37	7 10.5	43.6	140.6	6 24.1	44.0	140.7	5 37.7	44.5	140.8	4 51.2	45.0	140.8	37
38	6 26.9	43.6	141.3	5 40.1	44.1	141.4	4 53.2	44.5	141.4	4 06.2	44.9	141.5	38
39	5 43.3	43.7	142.0	4 56.0	44.1	142.1	4 09.7	44.6	142.1	3 21.3	45.0	142.2	39
40	4 59.6	43.7	142.7	4 11.9	44.2	142.8	3 24.1	44.6	142.8	2 36.3	45.0	142.8	40
41	4 15.9	43.8	143.4	3 27.7	44.2	143.4	2 39.5	44.6	143.5	1 51.3	45.0	143.5	41
42	3 32.1	43.8	144.1	2 43.5	44.2	144.1	1 54.9	44.6	144.1	1 06.3	45.0	144.1	42
43	2 48.3	43.8	144.8	1 59.3	44.2	144.8	1 10.3	44.6	144.8	0 21.3	45.1	144.8	43
44	2 04.5	43.8	145.4	1 15.1	44.3	145.5	0 25.7	44.7	145.5	0 23.8	45.0	34.5	44
45	1 20.7	43.9	146.1	0 30.8	44.2	146.1	0 19.0	44.6	33.9	1 08.8	45.0	33.9	45
46	0 36.8	43.8	146.8	0 13.4	44.2	33.2	1 03.6	44.6	33.2	1 53.8	45.0	33.2	46
47	0 07.0	43.9	32.5	0 57.6	44.3	32.5	1 48.2	44.6	32.5	2 38.8	45.0	32.5	47
48	0 50.9	43.9	31.8	1 41.9	44.2	31.8	2 32.8	44.6	31.9	3 23.8	45.0	31.9	48
49	1 34.8	43.8	31.1	2 26.1	44.2	31.2	3 17.4	44.6	31.2	4 08.8	44.9	31.2	49
50	2 18.6	43.8	30.5	3 10.3	44.2	30.5	4 02.0	44.5	30.5	4 53.7	44.9	30.6	50
51	3 02.4	43.8	29.8	3 54.5	44.1	29.8	4 46.5	44.5	29.8	5 38.6	44.8	29.9	51
52	3 46.2	43.7	29.1	4 38.6	44.1	29.1	5 31.0	44.5	29.2	6 23.4	44.8	29.2	52
53	4 29.9	43.8	28.4	5 22.7	44.1	28.4	6 15.5	44.3	28.5	7 08.2	44.7	28.6	53
81	24 13.9	39.7	7.8	25 13.4	39.8	7.8	26 12.8	39.9	7.9	27 12.2	40.0	8.0	81
82	24 53.6	39.4	6.9	25 53.2	39.4	7.0	26 52.7	39.6	7.1	27 52.2	39.7	7.1	82
83	25 33.0	39.1	6.1	26 32.6	39.2	6.2	27 32.3	39.3	6.2	28 31.9	39.4	6.3	83
84	26 12.1	38.8	5.3	27 11.8	38.9	5.3	28 11.6	38.9	5.4	29 11.3	39.0	5.4	84
85	26 50.9	38.5	4.4	27 50.7	38.6	4.5	28 50.5	38.6	4.5	29 50.3	38.7	4.5	85
86	27 29.4	38.2	3.6	28 29.3	38.2	3.6	29 29.1	38.3	3.6	30 29.0	38.4	3.7	86
87	28 07.6	37.8	2.7	29 07.5	37.9	2.7	30 07.4	37.9	2.7	31 07.4	37.9	2.8	87
88	28 45.4	37.5	1.8	29 45.4	37.5	1.8	30 45.3	37.6	1.8	31 45.3	37.6	1.9	88
89	29 22.9	37.1	0.9	30 22.9	37.1	0.9	31 22.9	37.1	0.9	32 22.9	37.1	0.9	89
90	30 00.0	36.7	0.0	31 00.0	36.7	0.0	32 00.0	36.7	0.0	33 00.0	36.7	0.0	90

Dec.	34° Hc	34° d	34° Z	35° Hc	35° d	35° Z	36° Hc	36° d	36° Z	37° Hc	37° d	37° Z	Dec.
°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	30 41.5	39.2	113.6	30 17.2	40.0	114.1	29 52.4	40.8	114.7	29 27.1	41.6	115.2	0
1	30 02.3	39.6	114.5	29 37.2	40.4	115.0	29 11.6	41.2	115.5	28 45.5	41.9	116.0	1
2	29 22.7	39.8	115.3	28 56.8	40.7	115.8	28 30.4	41.4	116.3	28 03.6	42.2	116.8	2
3	28 42.9	40.2	116.2	28 16.1	40.9	116.7	27 49.0	41.8	117.2	27 21.4	42.5	117.6	3
4	28 02.7	40.5	117.0	27 35.2	41.3	117.5	27 07.2	42.0	118.0	26 38.9	42.7	118.4	4
5	27 22.2	40.8	117.9	26 53.9	41.5	118.3	26 25.2	42.2	118.8	25 56.2	43.0	119.2	5
6	26 41.4	41.1	118.7	26 12.4	41.8	119.1	25 43.0	42.6	119.6	25 13.2	43.2	120.0	6
7	26 00.3	41.3	119.5	25 30.6	42.1	119.9	25 00.4	42.7	120.3	24 30.0	43.5	120.7	7
8	25 19.0	41.6	120.3	24 48.5	42.3	120.7	24 17.7	43.0	121.1	23 46.5	43.7	121.5	8
9	24 37.4	41.9	121.1	24 06.2	42.5	121.5	23 34.7	43.2	121.9	23 02.8	43.8	122.2	9
10	23 55.5	42.0	121.9	23 23.7	42.8	122.3	22 51.5	43.5	122.6	22 19.0	44.1	123.0	10
11	23 13.5	42.4	122.7	22 40.9	43.0	123.0	22 08.0	43.6	123.4	21 34.9	44.3	123.7	11
12	22 31.1	42.5	123.4	21 57.9	43.2	123.8	21 24.4	43.8	124.1	20 50.6	44.4	124.4	12
13	21 48.6	42.7	124.2	21 14.7	43.3	124.5	20 40.6	44.0	124.8	20 06.2	44.6	125.2	13
14	21 05.9	43.0	125.0	20 31.4	43.6	125.3	19 56.6	44.2	125.6	19 21.6	44.8	125.9	14
15	20 22.9	43.1	125.7	19 47.8	43.7	126.0	19 12.4	44.3	126.3	18 36.8	45.0	126.6	15
16	19 39.8	43.3	126.4	19 04.1	43.9	126.7	18 28.1	44.5	127.0	17 51.8	45.0	127.3	16
17	18 56.5	43.4	127.2	18 20.2	44.1	127.4	17 43.6	44.7	127.7	17 06.8	45.3	128.0	17
18	18 13.1	43.7	127.9	17 36.1	44.2	128.2	16 58.9	44.8	128.4	16 21.5	45.3	128.6	18
19	17 29.4	43.8	128.6	16 51.9	44.4	128.9	16 14.1	44.9	129.1	15 36.2	45.5	129.3	19
20	16 45.6	43.9	129.3	16 07.5	44.5	129.6	15 29.2	45.1	129.8	14 50.7	45.6	130.0	20
21	16 01.7	44.1	130.1	15 23.0	44.6	130.3	14 44.1	45.2	130.5	14 05.1	45.7	130.7	21
22	15 17.6	44.2	130.8	14 38.4	44.8	131.0	13 58.9	45.2	131.2	13 19.4	45.8	131.3	22
23	14 33.4	44.3	131.5	13 53.6	44.9	131.6	13 13.7	45.4	131.8	12 33.6	45.9	132.0	23
36	4 49.9	45.3	140.2	4 03.8	45.7	140.3	3 17.7	46.2	140.3	2 31.5	46.6	140.3	36
37	4 04.6	45.3	140.9	3 18.1	45.8	140.9	2 31.5	46.2	141.0	1 44.9	46.7	141.0	37
38	3 19.3	45.4	141.5	2 32.3	45.8	141.6	1 45.3	46.3	141.6	0 58.2	46.6	141.6	38
39	2 33.9	45.4	142.2	1 46.5	45.8	142.2	0 59.0	46.2	142.2	0 11.6	46.6	142.2	39
40	1 48.5	45.4	142.8	1 00.7	45.9	142.9	0 12.8	45.7	142.9	0 35.0	46.6	37.1	40
41	1 03.1	45.5	143.5	0 14.8	45.8	143.5	0 33.4	46.2	36.5	1 21.6	46.6	36.5	41
42	0 17.6	45.4	144.2	0 31.0	45.8	35.8	1 19.6	46.2	35.9	2 08.2	46.6	35.9	42
43	0 27.8	45.4	35.2	1 16.8	45.8	35.2	2 05.8	46.2	35.2	2 54.8	46.6	35.2	43
44	1 13.2	45.4	34.5	2 07.6	45.8	34.6	2 52.0	46.2	34.6	3 41.4	46.6	34.6	44
45	1 58.6	45.4	33.9	2 48.4	45.8	33.9	3 38.2	46.2	33.9	4 28.0	46.5	34.0	45
46	2 44.0	45.4	33.2	3 34.2	45.7	33.3	4 24.4	46.1	33.3	5 14.5	46.5	33.3	46
47	3 29.4	45.3	32.6	4 19.9	45.8	32.6	5 10.5	46.0	32.7	6 01.0	46.4	32.7	47
48	4 14.7	45.4	31.9	5 05.7	45.6	32.0	5 56.5	46.1	32.0	6 47.4	46.4	32.1	48
49	5 00.1	45.2	31.3	5 51.3	45.7	31.3	6 42.6	46.0	31.4	7 33.8	46.3	31.4	49
50	5 45.3	45.3	30.6	6 37.0	45.5	30.7	7 28.6	45.9	30.7	8 20.1	46.3	30.8	50
51	6 30.6	45.1	29.9	7 22.5	45.6	30.0	8 14.5	45.8	30.1	9 06.4	46.2	30.1	51
52	7 15.7	45.2	29.3	8 08.1	45.4	29.3	9 00.3	45.8	29.4	9 52.6	46.1	29.5	52
53	8 00.9	45.0	28.6	8 53.5	45.4	28.7	9 46.1	45.7	28.8	10 38.7	46.0	28.9	53
81	28 11.7	40.1	8.0	29 11.1	40.2	8.1	30 10.5	40.3	8.2	31 09.8	40.5	8.3	81
82	28 51.8	39.8	7.2	29 51.3	39.9	7.3	30 50.8	40.0	7.3	31 50.3	40.1	7.4	82
83	29 31.6	39.4	6.3	30 31.2	39.6	6.4	31 30.8	39.7	6.5	32 30.4	39.8	6.5	83
84	30 11.0	39.2	5.5	31 10.8	39.2	5.5	32 10.5	39.3	5.6	33 10.2	39.4	5.6	84
85	30 50.2	38.7	4.6	31 50.0	38.8	4.6	32 49.8	38.8	4.7	33 49.6	38.9	4.7	85
86	31 28.9	38.4	3.7	32 28.8	38.4	3.7	33 28.6	38.5	3.8	34 28.5	38.6	3.8	86
87	32 07.3	38.0	2.8	33 07.2	38.0	2.8	34 07.1	38.1	2.9	35 07.1	38.1	2.9	87
88	32 45.3	37.5	1.9	33 45.2	37.6	1.9	34 45.2	37.6	1.9	35 45.2	37.6	1.9	88
89	33 22.8	37.2	0.9	34 22.8	37.2	1.0	35 22.8	37.2	1.0	36 22.8	37.2	1.0	89
90	34 00.0	36.7	0.0	35 00.0	36.7	0.0	36 00.0	36.7	0.0	37 00.0	36.7	0.0	90

S. Lat. { L.H.A. greater than 180° ..... Zn = 180° − Z
L.H.A. less than 180° ..... Zn = 180° + Z

LATITUDE SAME NAME AS DECLINATION **L.H.A. 128°, 232°**

26NVM035

Figure 9-4. Pub 229 next higher LHA to find Z Diff.

Tab Z	Drop the value from Tab Z.	129.1
Exact Z (-360)	Apply the Total Corr to Tab Z (- 0.10).	129.0
Exact Zn	On each page of Pub 229 are small notes that state: In N. Lat. if LHA is **Greater than 180 then Zn= Z** if LHA is **Less than 180 then Zn= 360-Z** In S. Lat. if LHA is **Greater than 180 then Zn= 180-Z** if LHA is **Less than 180 then Zn= 180+Z** Our Lat is N. and LHA is **less than 180,** therefore Zn=360 - 129 or 231°.	231.0
Gyro Bearing	Enter the gyro bearing from the observation.	231.6
Gyro Error	Find the difference between Exact Zn and the gyro bearing and name the error. If the gyro bearing is less than the Exact Zn, the error is easterly, if more than Exact Zn, it's westerly. Use this memory aid: Gyro least - error east, Gyro best - error west.	0.6 West

We have now used the Sun to find the error on our gyrocompass. As stated before, a greater degree of accuracy can be obtained by making several observations and then working the solutions and averaging the results. This may seem a bit tedious, however, you may work all observations at once. This is easily accomplished by entering data in the strip form in stages.

Try this method. First enter GMT DR Lat, DR Long, GHA, Dec, and d#. Next find Incements (m/s), LHA, and True Dec. Now find your leftover values for Dee Inc, Lat Inc, and LHA Inc and enter Pub 229.

Once you have completed the solutions for all obsvervations, you can average the results. Here's an example:

Error 1 = .6 W Error 2 = .5 W Error 3 = .7 W for a total of 1.8 ÷ 3 = .6 W

Azimuth by Polaris

Azimuth by Polaris

Polaris (the North Star) is always within about 2° of true north. The true azimuth of Polaris is tabulated in the *Nautical Almanac* in the Polaris Tables for northern latitudes up to 65°.

Gathering Information: The entering arguments for the Polaris Tables are the LHA of Aries (GHA of Aries plus east longitude or minus west longitude) and latitude (at intervals of 5°, 10° or 20°). An extract from the *Nautical Almanac* Polaris azimuth table, which appears at the foot of the Polaris Tables, is shown in figure 9-5. As you can see, the interpolation can be done by visual inspection of the appropriate LHA and latitude.

The normal use of Polaris for obtaining compass error is when your ship is in the lower northern latitudes. This allows you to take a bearing on Polaris using the telescopic alidade. Since the computation and interpolation of azimuth by Polaris are relatively simple, we will not go into step-by-step procedures in this text.

POLARIS (POLE STAR) TABLES, 1983 275

FOR DETERMINING LATITUDE FROM SEXTANT ALTITUDE AND FOR AZIMUTH

L.H.A. ARIES	120°– 129°	130°– 139°	140°– 149°	150°– 159°	160°– 169°	170°– 179°	180°– 189°	190°– 199°	200°– 209°	210°– 219°	220°– 229°	230°– 239°
Lat.	AZIMUTH											
°	°	°	°	°	°	°	°	°	°	°	°	°
0	359·2	359·2	359·2	359·3	359·4	359·5	359·6	359·7	359·9	0·0	0·2	0·3
20	359·1	359·2	359·2	359·3	359·4	359·5	359·6	359·7	359·9	0·0	0·2	0·3
40	358·9	359·0	359·0	359·1	359·2	359·3	359·5	359·7	359·8	0·0	0·2	0·4
50	358·7	358·8	358·8	358·9	359·1	359·2	359·4	359·6	359·8	0·0	0·2	0·5
55	358·6	358·6	358·7	358·8	359·0	359·1	359·3	359·6	359·8	0·0	0·3	0·5
60	358·4	358·4	358·5	358·6	358·8	359·0	359·2	359·5	359·8	0·0	0·3	0·6
65	358·1	358·1	358·2	358·4	358·6	358·8	359·1	359·4	359·7	0·0	0·4	0·7

26NVM036

Figure 9-5. Extract from the *Nautical Almanac* Polaris Tables.

Amplitude of the Sun

Amplitude

An amplitude of the Sun or other celestial body can be used to determine gyro error. An amplitude (A) is the arc of the horizon between the prime vertical circle (the vertical circle through the east end west points of the horizon) and the observed body. The prime vertical circle may be true or magnetic depending upon which east or west points are involved. If the body is observed when its center is on the celestial horizon, the amplitude can be taken directly from table 27 of *Bowditch,* Volume II.

Horizions

The celestial horizon differs from the one you see (the visible horizon) because it runs through the center of Earth. There are a lot of computations that must be done to determine the celestial horizon of a body, but for now we will just say that it is the horizon that a navigator uses for all celestial computations.

When the center of the Sun is on the celestial horizon, its lower limb (lower edge) is about two-thirds of the diameter of the Sun above the visible horizon. When the center of the Moon is on the celestial horizon, its upper limb (upper edge) is on the visible horizon.

Figure 9-6 shows the relationship of the visible horizon to the celestial horizon. When planets and stars are on the celestial horizon, they are a little more than one Sun diameter above the visible horizon.

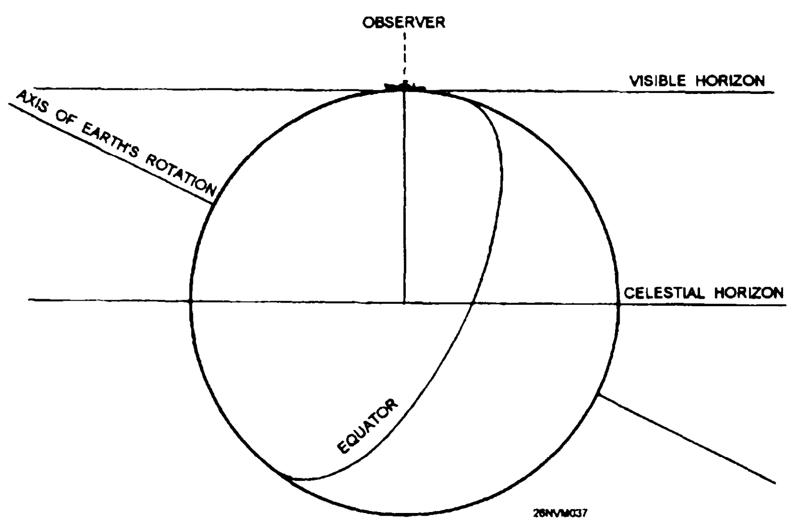

Figure 9-6. The visible and celestial horizons.

Amplitude of the Sun, Continued

Labeling the Amplitude

The amplitude of a body is given the prefix E (east) if the body is rising and the prefix W (west) if the body is setting. Additionally, the amplitude of a body is given the suffix N (north) if the body has northerly declination and the suffix S (south) if it has southerly declination.

Finding Amplitude of the Sun Using the Celestial Horizion

As discussed above, the amplitude of a body can be taken directly from table 27 of *Bowditch,* Volume II, if the body is observed when its center is on the celestial horizon. Since the Sun is most commonly used for amplitudes, it will be the topic of our discussion.

Gathering Information: To observe the Sun when it is on the celestial horizon, its lower limb must be about two-thirds of the diameter above the visible horizon. You must know the Greenwich mean time (GMT) of your observation to determine the Sun's declination from the right-hand daily pages of the *Nautical Almanac,* your DR Lat. at the time of observation, and the true bearing of the Sun as observed using a telescopic alidade.

Example Problem

The DR latitude of your ship is 51°04.6'N. The declination of the setting Sun was 19°00.4'N. Your true bearing (as observed by a telescopic alidade) to the Sun was 300°.

From this known information, we can use table 27 of *Bowditch* to determine the amplitude.

Figure 9-7 shows an excerpt from table 27. By inspection of figure 9-7, you can see that you must enter the left-hand column with your ship's DR latitude. You can also see that the Sun's declination is listed across the top of the table. Since latitude 51° and declination 19° are closest to our entering values, we determine that the amplitude of the Sun when it is on the celestial horizon is 31.2°. Now that we have the amplitude, what do we do with it? First of all, there are some basic rules that must be applied that relate to our previous discussion of the assigned prefix and suffix of an amplitude. Our amplitude was taken when the Sun was setting, and its declination name is north. Using the rules for labeling the amplitude, we label the amplitude as follows: W 31.2° N. We use W because the Sun is setting and N because the Sun's declination is N.

TABLE 27
Amplitudes

Latitude	Declination 18°0	18°5	19°0	19°5	20°0	20°5	21°0	21°5	22°0	22°5	23°0	23°5	24°0	Latitude
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	18. 0	18. 5	19. 0	19. 5	20. 0	20. 5	21. 0	21. 5	22. 0	22. 5	23. 0	23. 5	24. 0	0
10	18. 3	18. 8	19. 3	19. 8	20. 3	20. 8	21. 3	21. 8	22. 4	22. 9	23. 4	23. 9	24. 4	10
15	18. 7	19. 2	19. 7	20. 2	20. 7	21. 3	21. 8	22. 3	22. 8	23. 3	23. 9	24. 4	24. 9	15
20	19. 2	19. 7	20. 3	20. 8	21. 3	21. 9	22. 4	23. 0	23. 5	24. 0	24. 6	25. 1	25. 6	20
25	19. 9	20. 5	21. 1	21. 6	22. 2	22. 7	23. 3	23. 9	24. 4	25. 0	25. 5	26. 1	26. 7	25
30	20. 9	21. 5	22. 1	22. 7	23. 3	23. 9	24. 4	25. 0	25. 6	26. 2	26. 8	27. 4	28. 0	30
32	21. 4	22. 0	22. 6	23. 2	23. 8	24. 4	25. 0	25. 6	26. 2	26. 8	27. 4	28. 0	28. 7	32
34	21. 9	22. 5	23. 1	23. 7	24. 4	25. 0	25. 6	26. 2	26. 9	27. 5	28. 1	28. 7	29. 4	34
36	22. 5	23. 1	23. 7	24. 4	25. 0	25. 7	26. 3	26. 9	27. 6	28. 2	28. 9	29. 5	30. 2	36
38	23. 1	23. 7	24. 4	25. 1	25. 7	26. 4	27. 1	27. 7	28. 4	29. 1	29. 7	30. 4	31. 1	38
40	23. 8	24. 5	25. 2	25. 8	26. 5	27. 2	27. 9	28. 6	29. 3	30. 0	30. 7	31. 4	32. 1	40
41	24. 2	24. 9	25. 6	26. 3	26. 9	27. 6	28. 3	29. 1	29. 8	30. 5	31. 2	31. 9	32. 6	41
42	24. 6	25. 3	26. 0	26. 7	27. 4	28. 1	28. 8	29. 5	30. 3	31. 0	31. 7	32. 5	33. 2	42
43	25. 0	25. 7	26. 4	27. 2	27. 9	28. 6	29. 3	30. 1	30. 8	31. 6	32. 3	33. 0	33. 8	43
44	25. 4	26. 2	26. 9	27. 6	28. 4	29. 1	29. 9	30. 6	31. 4	32. 1	32. 9	33. 7	34. 4	44
45	25. 9	26. 7	27. 4	28. 2	28. 9	29. 7	30. 5	31. 2	32. 0	32. 8	33. 5	34. 3	35. 1	45
46	26. 4	27. 2	27. 9	28. 7	29. 5	30. 3	31. 1	31. 8	32. 6	33. 4	34. 2	35. 0	35. 8	46
47	26. 9	27. 7	28. 5	29. 3	30. 1	30. 9	31. 7	32. 5	33. 3	34. 1	35. 0	35. 8	36. 6	47
48	27. 5	28. 3	29. 1	29. 9	30. 7	31. 6	32. 4	33. 2	34. 0	34. 9	35. 7	36. 6	37. 4	48
49	28. 1	28. 9	29. 8	30. 6	31. 4	32. 3	33. 1	34. 0	34. 8	35. 7	36. 6	37. 4	38. 3	49
50	28. 7	29. 6	30. 4	31. 3	32. 1	33. 0	33. 9	34. 8	35. 6	36. 5	37. 4	38. 3	39. 3	50
51	29. 4	30. 3	31. 2	32. 0	32. 9	33. 8	34. 7	35. 6	36. 5	37. 5	38. 4	39. 3	40. 3	51
52	30. 1	31. 0	31. 9	32. 8	33. 7	34. 7	35. 6	36. 5	37. 5	38. 4	39. 4	40. 4	41. 3	52
53	30. 9	31. 8	32. 8	33. 7	34. 6	35. 6	36. 5	37. 5	38. 5	39. 5	40. 5	41. 5	42. 5	53
54	31. 7	32. 7	33. 6	34. 6	35. 6	36. 6	37. 6	38. 6	39. 6	40. 6	41. 7	42. 7	43. 8	54
70. 0	64. 6	68. 1	72. 2	77. 4	90. 0									70. 0
70. 5	67. 8	71. 9	77. 2	90. 0										70. 5
71. 0	71. 7	77. 1	90. 0											71. 0
71. 5	76. 9	90. 0												71. 5
72. 0	90. 0													72. 0

26NVM038

Figure 9-7. Excerpt from table 27.

Finding Amplitude of the Sun Using the Celestial Horizion, continued

With the amplitude properly labeled, we can now follow another set of rules to determine the azimuth.

Rules:

1. Rising Sun with north declination, subtract the amplitude from 090°
2. Rising Sun with south declination, add the amplitude to 090°
3. Setting Sun with north declination, add the amplitude to 270°
4. Setting Sun with south declination, subtract the amplitude from 270°

By following the rules above, our amplitude can now be converted to an azimuth as follows:

W31.2°N + 270° = 301.2°

Our true bearing to the Sun was 300°. Gyro error can be determined as follows:

301.2° (azimuth)
300.0° (gyro bearing)
1.2 °E (gyro error)

We find the name of the error by using our memory aid

Gyro least - error EAST, Gyro best - error WEST.

Finding Amplitude Using the Visible Horizion

If the body is observed when its center is on the visible horizon, a correction from table 28 of *Bowditch,* Volume II, is applied to the value taken from *Bowditch's* table 27. Refer to table 28 for step-by-step instructions.

The Celestial LOP

General Information

You have seen how lines of position, obtained through bearings on terrestrial objects, are used to fix a ship's position in piloting. You know that a line of position (LOP) is a locus of possible positions of the ship. In other words, the ship's position must be somewhere along that line. A fix, by definition, is a relatively accurate determination of latitude and longitude. In practice, this position is the intersection of two or more lines of position; but often it is not the ship's exact position because you can always assume some errors in observation, plotting, and the like.

The celestial navigator must establish lines of position by applying the results of observations of heavenly bodies. A line of position obtained at one time may be used at a later time. All you need to do is move the line parallel to itself, a distance equal to the run of the ship in the interim, and in the same direction as the run. Such a line of position cannot be as accurate as a new line because the amount and direction of its movement can be determined only by the usual DR methods. If two new lines cannot be obtained, however, an old line, advanced and intersected with a new one, may be the only possible way of establishing a fix. Naturally, the distance an old line may be advanced without a substantial loss of accuracy depends on how closely the run can be reckoned.

In celestial navigation, as in piloting, you essentially are trying to establish the intersection of two or more lines of position. A single observation and the resulting LOP is insufficient to obtain a fix.

The most accurate method of obtaining a celestial fix is to take sights on many bodies in a short time. For example, it is quite common to take sights on six or more stars in a period of 15 minutes or less. Taking sights on many bodies allows the observer to identify and throw out LOPS with obvious errors.

Determining the LOP

You might be entitled to complain that much has been said concerning what an LOP tells you, but very little has been told about how you determine it in the first place. We are coming to that part now.

The first item is to take on a heavenly body or bodies and then reduce the sights. Reducing the sights taken gives you the information you need to plot the LOP. The LOPS then gives you the resulting fix.

Determining the LOP, continued

Figure 9-8 illustrates the method used in establishing a single LOP by observing a star. An assumed position (AP) is selected according to certain requirements of convenience in calculating (described later). Observation of a star provides sextant altitude (hs). Sextant altitude is then corrected to obtain observed altitude (Ho). The star's altitude from the assumed position, called the computed altitude (Hc), and its azimuth angle are determined from tables by a procedure you will soon learn. The azimuth angle is then converted to azimuth. After selecting an AP, draw the azimuth through the AP. Along the azimuth, measure off the altitude intercept (difference between the observed altitude and the computed altitude). At the end of this measurement, draw a perpendicular line, which is the LOP. You must know whether altitude intercept (a) should be measured from AP toward the body or from AP measured away from the body. It is helpful to remember the initials Ho MO To, if Ho is more toward. This means that if Ho is greater than Hc measure altitude intercept (a) from AP toward the body. If Hc is greater than Ho measure altitude intercept (b) from AP away from the body.

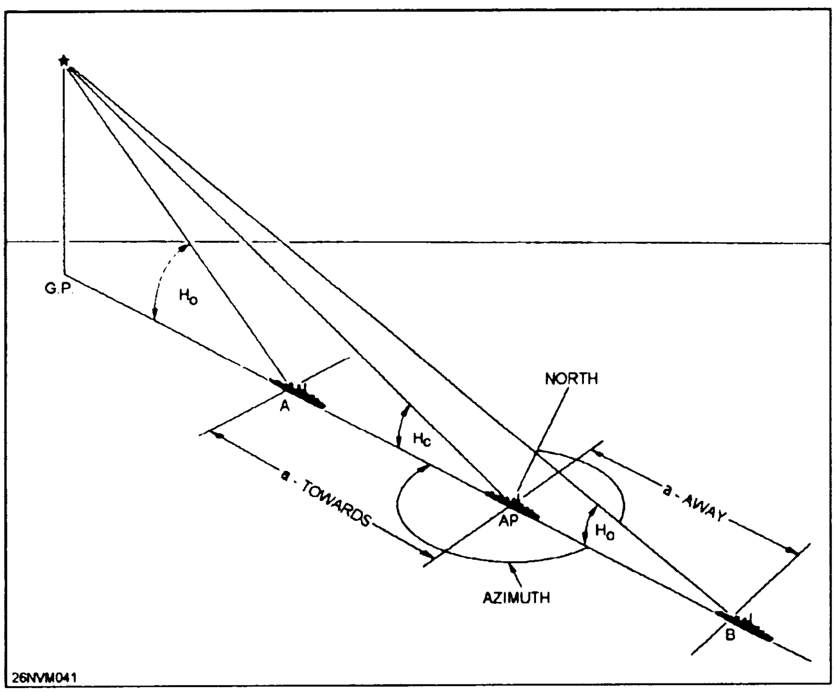

Figure 9-8. Determining a LOP.

Using the Sextant

General

The sextant is the instrument of chief importance in celestial navigation. It is used to measure the altitude of a heavenly body above the visible horizon. Sextant altitude is corrected for various factors to determine the body's true (or corrected) altitude above the celestial horizon.

Techniques

Here are some techniques commonly used to take sights with the marine sextant. It will always be necessary to find any index error prior to taking sights; refer to chapter 8 to find index error.

Use the following step action table for the general steps to take sights on the Sun. The steps for stars and planets are basically the same, except you would omit steps 2 and 4.

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1.</td><td>Hold the sextant level with the horizon and determine index error.</td></tr>
<tr><td>2.</td><td>CAUTION: Set shade filters in place now, or eye burns may result.</td></tr>
<tr><td>3.</td><td>Aim the sextant to a point on the horizion directly below the Sun.</td></tr>
<tr><td>4.</td><td><table>
<tr><th>IF...</th><th>THEN...</th></tr>
<tr><td>the Sun is rising</td><td>Move the index arm slowly outward from the 0° position until the Sun's lower limb is just below the horizon.</td></tr>
<tr><td>the Sun is setting</td><td>Move the index arm slowly outward from the 0° position until the Sun's lower limb is just above the horizon.</td></tr>
</table></td></tr>
<tr><td>5.</td><td>Swing the arc. This means to gently move your hand grasping the sextant handle in a small upward arcing motion. Up to the left, then back to the right. You will see the reflected image of the Sun arc back and forth.</td></tr>
<tr><td>6.</td><td>Give the recorder a standby to mark (marking the exact time of the sight). Continue swinging the arc while turning the micrometer drum slightly until the lower limb of the Sun touches the horizon. At that exact moment, mark the time of the sight and record the sextant altitude.</td></tr>
</table>

Altitude Corrections

Altitude Corrections

Of the following five altitude corrections, the first three apply to observations of all celestial bodies. The last two corrections are applicable only when the observed body belongs to the solar system. Figure 9-9 illustrates the correction problem. To obtain the true altitude, you must correct the sextant altitude of any celestial body for:

1. **Index error,** which is the constant instrument error caused by a lack of perfect parallelism between the index mirror and horizon glass when the sextant is set at 0°.

2. **Refraction,** which is the deviation of rays of light from a straight line caused by Earth's atmosphere.

3. **Dip of the horizon,** which is the difference in direction between the visible and celestial horizons caused by the observer's height above the surface.

If the observed body belongs to the solar system, corrections must also be made for:

4. **Parallax,** which is caused by the proximity of bodies of the solar system to Earth, resulting in a difference in altitudes measured from the surface of Earth and from the center of Earth. Such an occurrence is not true of other heavenly bodies whose distance from Earth is considered infinite.

5. **Semidiameter,** which results from the nearness of bodies of the solar system, which makes it necessary to consider the observed bodies as appreciable size instead of as mere points of light; for example, stars. The sextant altitude of such a body is obtained by bringing its disk tangent to the horizon. Semidiameter correction must be applied to find the altitude of the center.

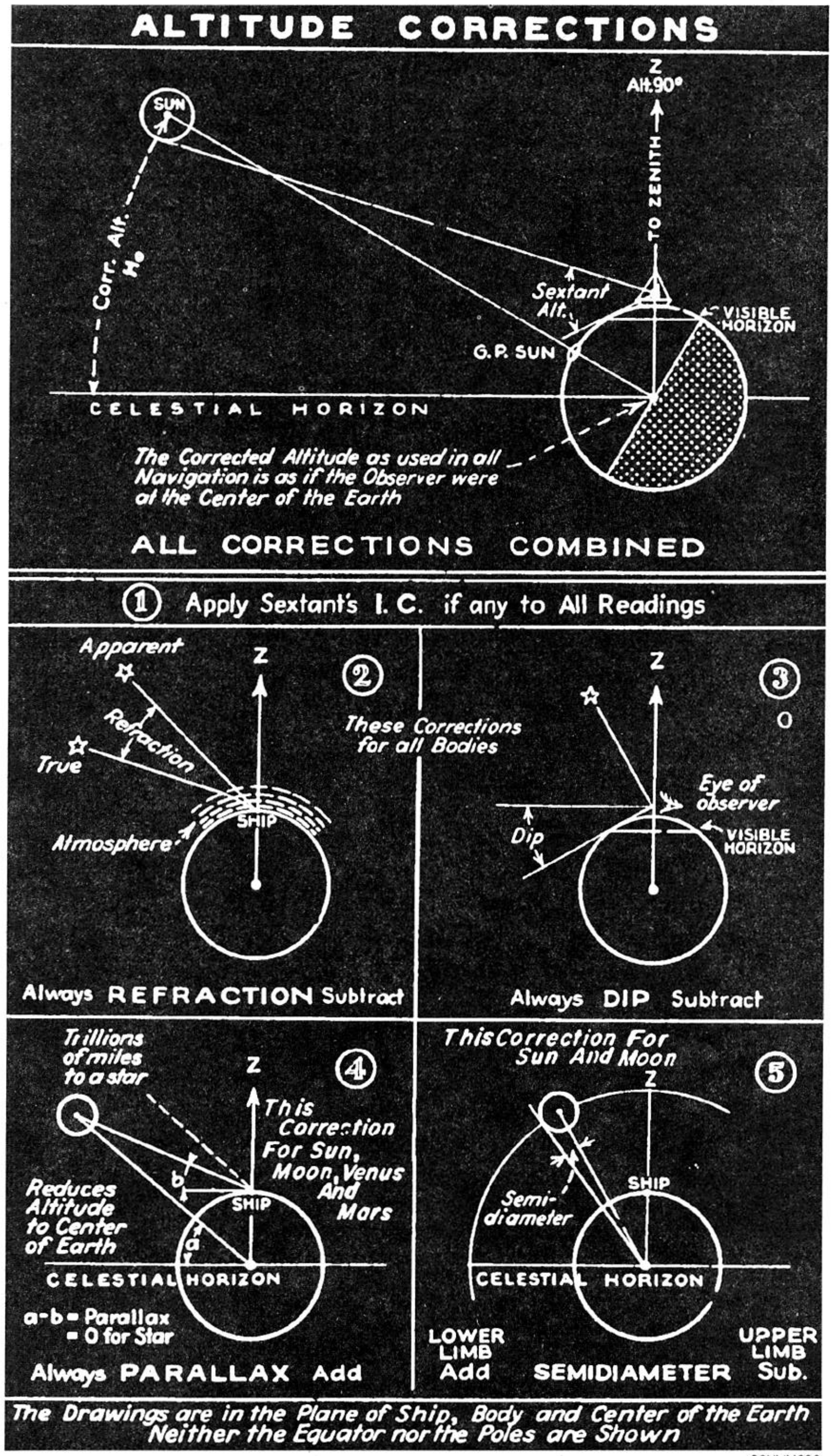

Figure 9-9. Sextant altitude corrections.

Corrections Defined We will explore each altitude correction in detail. Applying altitude corrections is the starting point for reducing sights for any observation.

Name	Description
Index Error	The amount of instrument error in the sextant (covered in chapter 8).
Refraction	Earth is wrapped in a blanket of atmosphere more than 50 miles deep. Density of the atmosphere, like that of the ocean, increases with depth and is greatest at the bottom, next to Earth's surface. Light rays do not follow a straight line when passing through atmosphere of different densities, but are slightly bent into a gentle arc. This phenomenon is called refraction. Refraction is defined as the deviation of light rays from a straight line caused by their passage obliquely through mediums of different density. The measure of refraction is the angular difference between the apparent rays of light from an observed celestial body and its true direction. The effect of refraction is always to make the observed altitude greater than the true altitude. Consequently, refraction correction is always subtracted from the sextant altitude. Since refraction is caused by the oblique passage of rays through the atmosphere, rays from a body in the observer's zenith, intersecting the atmosphere at right angles, are not refracted. Maximum refraction occurs when a body is on the horizon, amounting then to between 34 and 39 minutes of arc. The amount of refractions depends on atmospheric conditions. Density of the atmosphere varies with barometric pressure and temperature. Refraction varies with density and also with the body's altitude. Because refraction varies with atmospheric conditions, and the effect of atmospheric conditions at low altitudes cannot be estimated with complete accuracy, observations of bodies below 10° should be regarded with suspicion. Refraction has no effect on the azimuth of a celestial body because it takes place entirely in the vertical plane of passage of the light rays.
Dip	The higher an observer's position is above the surface of the Earth, the more he/she must lower (or dip) the line of vision to see the horizon. Logically, then, all altitude observations must be corrected for the height of eye. Refer again to figure 9-9, and you will see why a dip correction is always subtracted. Failure to correct for dip from a height of 10 feet will result in an error of 3 miles in a line of position. From the bridge of the average destroyer, the resulting error would be approximately 10 miles.

Name	Description
Parallax	Parallax is the difference between the altitude of a body, as measured from Earth's center, and its altitude (corrected for refraction and dip) as measured from Earth's surface. Altitude from the center of Earth is bound to be greater than from the surface. Consequently parallax is always a plus correction. Parallax increases from 0° for a body directly overhead to a maximum for a body on the horizon. In the latter instance, it is called horizontal parallax (HP). Parallax of the Moon is both extreme and varied because of its changing distance from Earth in its passage through its orbit. Parallax of the Sun is small; parallax of the planets is even smaller. For the stars, parallax is so tiny it is negligible.
Semidiameter	The true altitude of a body is measured to the center of that body. Because the Sun and Moon are of appreciable size, the usual practice is to observe the lower limb. Therefore, semidiameter correction must be added. It follows, then, that if the upper limb of either body is observed, the semidiameter correction is subtractive. Semidiameter correction amounts to about 16 minutes of arc for either the Sun or Moon. Stars are considered as points, and they require no semidiameter correction. When observing a planet, the center of the planet is visually estimated by the observer, so there is never a semidiameter correction.

Remarks

In concluding the subject of altitude corrections, remember that **some tables** for altitude corrections (the *Nautical Almanac*, for example) combine two or more of the corrections for refraction, parallax, and semidiameter.

The correction for height of eye (dip) appears in a separate table for use with all bodies. Index error, which is impossible to include in such tables, should always be determined, recorded, marked plus or minus, and applied before any of the tabulated corrections.

Strip Forms

The OPNAV Strip Form *3530/30; H.0 229; Nautical Almanac are* used to reduce sights for stars, planets, the Sun, and the Moon. The altitude corrections for each are the same except an additional correction is required for the Moon and planets. Reducing sights using this strip form is a process that can be broken down into the following stages:

Stage	Description
1.	Applying altitude corrections to find Ho (height observed).
2.	Using GMT to find LHA to enter Pub 229 with.
3.	Finding True Dee to enter Pub 229 with.
4.	Entering Pub 229 to find total corrections to apply to Ho to find Hc (height computed) Intercept, and Zn.

Steps to Follow to Find Ho

Use the following table to find Ho for any celestial body. Since we will be working several example problems, refer back to this table to find Ho.

Strip Form Pub 229 Naut Alm	Example problem to find Ho Action	Complete Strip Form Pub 229 Naut Alm
Body	Enter the symbol of the body.	SUN
GMT	Enter the GMT of the actual sight.	09 15 38
IC	Enter the value of the index correction.	- 1.0
D	Enter the dip correction (height of eye) from the inside cover of the *Nautical Almanac.*	- 6.9
Sum	Total the IC and D correction.	- 7.9
hs	Enter the uncorrected sextant altitude from the sight.	25° 46.9'
ha	Apply the sum to hs.	25° 39.0'
Alt Corr	Use ha to enter the altitude correction tables of the *Nautical Almanac.*	+ 14.3’
Add'l Corr Moon Hp/corr	Add any additional corrections for the Moon or planets.	N/A
Ho	Apply altitude and add'l corr to ha.	25° 53.3'

How to Reduce a Sunline Using Pub 229

Gather Information

As with any celestial observation, you must gather data to reduce to an LOP. With a sextant and recorder you will need the following: date/GMT of sight, DR position, sextant altitude (hs), height of eye of the observer, and IC correction.

Procedure

For our example we will use the following:

Date: 31 March 1984 GMT: 09 15 38
Lat: 36° 32.8'N Long: 018° 10.0' W
hs: 25° 46.9' IC: - 1.0
Hgt of Eye: 50 ft

After applying altitude corrections we have determined Ho = 25° 53.3'.

We can now use the Pub 229 strip form to complete the process of reducing; at this point we have completed stage 1. We can move on to the next stage of finding LHA.

Notice that to find LHA, we follow the same steps as we did for our azimuth of the Sun problem only slightly different. Here's the key difference. We want to arrive at an even number LHA. To do this, we will use an assumed longitude. This step will help us in interpolation later in this problem. There is a catch though; the following rule must be adhered to when finding an assumed longitude.

Rule: The assumed longitude used as an assumed position must be within 30' of the original DR longitude.

Trick of the trade: When finding your assumed longitude, simply drop the minutes of total GHA down, then add the whole degree of longitude that is within 30' of the DR longitude. Look at our example problem where we dropped the 52.2' down from the total GHA. If we were to use the 18° from the original DR long. of 18° 10.0, which would be 18° 52.2' it would be more than 30', so we changed the 18° to 17° and all's well.

Let's begin working our problem on the next page.

OPNAV 3130/30 Pub 229 Naut Alm	ACTION	Completed Strip Form
Ho	Apply altitude corrections to find.	25° 53.3'
GHA(h)	Enter the GHA hour value from the *Nautical Almanac.*	313° 57.7'
Increment (m/s)	Enter the minutes and seconds value from the *Nautical Almanac.*	3° 54.5'
Total GHA	Add GHA(h) and Increments (m/s).	317° 52.2'
v/v corr SHA	ENTER SHA for stars or planets only.	STARS and PLANETS ONLY
a Long (+E, -W) (+ - 360° if needed)	Enter the assumed DR longitude to arrive at an even degree of LHA, add east and subtract west.	17° 52.2'W
LHA	LHA= Total GHA + (v/v or SHA for star and planets) +E or -W DR Long.	300° 00.0'
Tab Dee	Enter the tabulated declination for 07 hours on the Sun column from *Nautical Almanac.*	N 4° 17.3'
d# / D Corr^n	The d# is found at the bottom of the Sun Dee column; in this case it is +1.0. It is assigned a + because dec is increasing. The D corr is found on the Increments and Corrections page for 15m38s. Look under the *v* or *d* column for the d# (1.0) and record the Corr^n value (0.4). The D Corr^n assumes the same sign as the d#.	+0.6 / +0.3'
True Dec	Apply the D Corr^n to Tab Dec	N 4° 17.6'
DR Lat same or contrary	Enter the whole degree of latitude and determine if it is named (N or S) as True Dec. In this case lat. is N and Dee is N, so it is same.	N 37° same

We have finished stages 2 and 3 and can move on to our final stage.

OPNAV 3130/30 Pub 229 Naut Alm	ACTION	Completed Strip Form
Dec Inc /d	Dec Inc = True Dec min. only / d = d from Pub 229 entered with whole degrees of LHA, Dec, and Lat. (See fig. 9-10.)	17.6 / +38.1
Tens / DSD	Enter from the Pub 229 interpolation tables located on the inside of the front and back cover. (See fig. 9-11.)	+ 8.8
Units / DSD corr	Same as above.	+ 2.4
Total Corr	Total of tens and units.	+ 11.2
Hc (Tab)	Enter from Pub 229.	26° 07.5'
Hc (Comp)	Apply Total Corr to Hc (Tab).	26° 18.7'
Ho	Drop Ho down from the top of the form.	25° 53.3'
a	Subtract the higher value of either Hc(Comp) or Ho from the other. In this case, Ho is subtracted from Hc(Comp). The A means away. We will fully explain Towards and Away when we plot the LOP.	A 25.4
Z	Enter from Pub 229. Apply the rules for 2 just as with our azimuth problem.	105.8
Zn	LHA is greater than 180 so Zn = Z.	105.8

We have now completed the sight reduction solution for a sunline. The goal was to obtain an LOP. Where is the LOP you ask? Everything we need is right here. We will use the Zn (true bearing), a (intercept), and assumed position to plot our LOP. Let's move on to that task right now.

How to Reduce a Sunline Using Pub 229, Continued

60°, 300° L.H.A. LATITUDE SAME NAME AS DECLINATION

N. Lat. {L.H.A. greater than 180°......Zn=Z; L.H.A. less than 180°..........Zn=360°−Z}

Dec.	30° Hc	30° d	30° Z	31°	32° Hc	32° d	32° Z	33° Hc	33° d	33° Z	34° Hc	34° d	34° Z	35° Hc	35° d	35° Z	36° Hc	36° d	36° Z	37° Hc	37° d	37° Z	Dec.
°	° ′	′	°	°	′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	° ′	′	°	°
0	25 39.5	+33.1	106.1	25	05.3	+35.0	107.0	24 47.6	+35.8	107.5	24 29.3	+36.8	107.9	24 10.7	+37.6	108.3	23 51.6	+38.4	108.7	23 32.1	+39.3	109.2	0
1	26 12.6	32.8	105.2	25	40.3	34.6	106.1	25 23.4	35.5	106.6	25 06.1	36.4	107.0	24 48.3	37.3	107.5	24 30.0	38.2	107.9	24 11.4	39.0	108.3	1
2	26 45.4	32.4	104.2	26	14.9	34.3	105.2	25 58.9	35.2	105.7	25 42.5	36.1	106.1	25 25.6	36.9	106.6	25 08.2	37.8	107.1	24 50.4	38.7	107.5	2
3	27 17.8	31.9	103.3	27 0	49.2	33.9	104.3	26 34.1	34.8	104.8	26 18.6	35.7	105.3	26 02.5	36.7	105.7	25 46.0	37.6	106.2	25 29.1	38.4	106.7	3
4	27 49.7	31.6	102.3	27 3	23.1	33.5	103.4	27 08.9	34.5	103.9	26 54.3	35.4	104.4	26 39.2	36.3	104.8	26 23.6	37.2	105.3	26 07.5	38.1	105.8	4
5	28 21.3	+31.2	101.4	28 0	56.6	+33.1	102.4	27 43.4	+34.1	102.9	27 29.7	+35.1	103.4	27 15.5	+36.0	103.9	27 00.8	+36.9	104.4	26 45.6	+37.8	104.9	5
6	28 52.5	30.8	100.4	28 4	29.7	32.8	101.5	28 17.5	33.8	102.0	28 04.8	34.7	102.5	27 51.5	35.6	103.0	27 37.7	36.5	103.6	27 23.4	37.4	104.1	6
7	29 23.3	30.3	99.4	29 1	02.5	32.3	100.5	28 51.3	33.3	101.1	28 39.5	34.3	101.6	28 27.1	35.3	102.1	28 14.2	36.2	102.7	28 00.8	37.1	103.2	7
8	29 53.6	29.9	98.4	29 4	34.8	32.0	99.6	29 24.6	32.9	100.1	29 13.8	33.9	100.7	29 02.4	34.9	101.2	28 50.4	35.9	101.8	28 37.9	36.8	102.3	8
9	30 23.5	29.4	97.4	30 1	06.8	31.4	98.6	29 57.5	32.5	99.1	29 47.7	33.5	99.7	29 37.3	34.4	100.3	29 26.3	35.4	100.8	29 14.7	36.4	101.4	9
10	30 52.9	+28.9	96.4	30 4	38.2	+31.1	97.6	30 30.0	+32.1	98.2	30 21.2	+33.0	98.8	30 11.7	+34.1	99.3	30 01.7	+35.1	99.9	29 51.1	+36.0	100.5	10
11			95.4	31 1	09.3	30.5	96.6						97.8							30 27.1	35.6	99.5	11
84	32 51.3									6.4	36 49.9					6.6	38 49.1	26.6	6.7				
85	32 24.0	−27.8	5.1	33 2	23.5	−27.6	5.2	35 23.3	−27.5	5.3	36 23.0	−27.4	5.4	37 22.8	−27.4	5.5	38 22.5	−27.3	5.5	39 22.2	−27.1	5.6	85
86	31 56.2	28.3	4.1	32 5	55.9	28.2	4.2	34 55.8	28.2	4.2	35 55.6	28.1	4.3	36 55.4	28.0	4.3	37 55.2	27.8	4.4	38 55.1	27.8	4.5	86
87	31 27.9	28.8	3.0	32 2	27.7	28.7	3.1	34 27.6	28.6	3.2	35 27.5	28.6	3.2	36 27.4	28.5	3.2	37 27.4	28.6	3.3	38 27.3	28.5	3.3	87
88	30 59.1	29.3	2.0	31	59.0	29.2	2.1	33 59.0	29.3	2.1	34 58.9	29.2	2.1	35 58.9	29.2	2.1	36 58.8	29.1	2.2	37 58.8	29.1	2.2	88
89	30 29.8	29.8	1.0	31	29.8	29.8	1.0	33 29.7	29.7	1.0	34 29.7	29.7	1.1	35 29.7	29.7	1.1	36 29.7	29.7	1.1	37 29.7	29.7	1.1	89
90	30 00.0	−30.2	0.0	3	00.0	−30.2	0.0	33 00.0	−30.3	0.0	34 00.0	−30.3	0.0	35 00.0	−30.3	0.0	36 00.0	−30.3	0.0	37 00.0	−30.3	0.0	90
	30°				32°			33°			34°			35°			36°			37°			

60°, 300° L.H.A. LATITUDE SAME NAME AS DECLINATION

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Figure 9-10. Excerpt from Pub 229.

INTERPOLATION TABLE

Dec. Inc.	Tens 10′	20′	30′	40′	50′	Decimals	Units 0′	1′	2′	3′	4′	5′	6′	7′	8′	9′	Double Second Diff. and Corr.
16.0	2.6	5.3	8.0	10.6	13.3	.0	0.0	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.2	2.5	
16.1	2.7	5.3	8.0	10.7	13.4	.1	0.0	0.3	0.6	0.9	1.1	1.4	1.7	2.0	2.2	2.5	
16.2	2.7	5.4	8.1	10.8	13.5	.2	0.1	0.3	0.6	0.9	1.2	1.4	1.7	2.0	2.3	2.5	1.0
16.3	2.7	5.4	8.1	10.9	13.6	.3	0.1	0.4	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	0.1 3.0
16.4	2.7	5.5	8.2	10.9	13.7	.4	0.1	0.4	0.7	0.9	1.2	1.5	1.8	2.0	2.3	2.6	0.2 4.9
16.5	2.8	5.5	8.3	11.0	13.8	.5	0.1	0.4	0.7	1.0	1.2	1.5	1.8	2.1	2.3	2.6	0.3 6.9
16.6	2.8	5.5	8.3	11.1	13.8	.6	0.2	0.4	0.7	1.0	1.3	1.5	1.8	2.1	2.4	2.6	0.4 8.9
16.7	2.8	5.6	8.4	11.2	13.9	.7	0.2	0.5	0.7	1.0	1.3	1.6	1.8	2.1	2.4	2.7	0.5 10.8
16.8	2.8	5.6	8.4	11.2	14.0	.8	0.2	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4	2.7	0.6 12.8
16.9	2.9	5.7	8.5	11.3	14.1	.9	0.2	0.5	0.8	1.1	1.3	1.6	1.9	2.2	2.4	2.7	0.7 14.8 0.8 16.7
17.0	2.8	5.6	8.5	11.3	14.1	.0	0.0	0.3	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	0.9 18.7
17.1	2.8	5.7	8.5	11.4	14.2	.1	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	1.0 20.7
17.2	2.8	5.7	8.6	11.4	14.3	.2	0.1	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	1.1 22.7
17.3	2.9	5.8	8.6	11.5	14.4	.3	0.1	0.4	0.7	1.0	1.3	1.5	1.8	2.1	2.4	2.7	1.2 24.6
17.4	2.9	5.8	8.7	11.6	14.5	.4	0.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	2.4	2.7	1.3 26.6 1.4 28.6
17.5	2.9	5.8	8.8	11.7	14.6	.5	0.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	2.5	2.8	1.5 30.5
17.6	2.9	5.9	8.8	11.7	14.7	.6	0.2	0.5	0.8	1.0	1.3	1.6	1.9	2.2	2.5	2.8	1.6 32.5
17.7	3.0	5.9	8.9	11.8	14.8	.7	0.2	0.5	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8	1.7 34.5
17.8	3.0	6.0	8.9	11.9	14.9	.8	0.2	0.5	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9	
17.9	3.0	6.0	9.0	12.0	15.0	.9	0.3	0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9	
23.5	3.9	7.8	11.8	[illegible]	19.6	.5	0.2	0.6	1.0	1.4	1.8	[illegible]	[illegible]	2.9	3.3	3.7	27.9 1.7
23.6	3.9	7.9	11.8	15.7	19.7	.6	0.2	0.6	1.0	1.4	1.8	2.2	2.6	3.0	3.4	3.8	29.6 1.8
23.7	4.0	7.9	11.9	15.8	19.8	.7	0.3	0.7	1.1	1.4	1.8	2.2	2.6	3.0	3.4	3.8	31.3 1.9
23.8	4.0	8.0	11.9	15.9	19.9	.8	0.3	0.7	1.1	1.5	1.9	2.3	2.7	3.1	3.4	3.8	33.0 2.0
23.9	4.0	8.0	12.0	16.0	20.0	.9	0.4	0.7	1.1	1.5	1.9	2.3	2.7	3.1	3.5	3.9	34.7
	10′	20′	30′	40′	50′		0′	1′	2′	3′	4′	5′	6′	7′	8′	9′	

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Figure 9-11. Interpolation table from the inside cover of Pub 229.

Plotting One or More LOPs

Procedure

Follow the steps in the table and refer to the accompanying figures to plot LOPs.

Step	Action
1.	Plot the AP (assumed position). This is the whole degree of latitude and the assumed longitude. In our example problem this would be Lat 37° 00.0' N Long 017° 52.2' W.
2.	Lay off the azimuth line (Zn) from the AP toward or away from the body, depending on whether the observed altitude (Ho) is greater or less than the computed altitude (Hc).
3.	Measure in the proper direction, along the azimuth line, the difference between the observed and the computed altitude in miles and tenths of miles. This is the value of a or intercept.
4.	Draw a line at the extremity of a, perpendicular (add 90° to Zn) to the azimuth line. At the time of observation, this perpendicular line is the LOP.
5.	Label the LOP with the time of observation and the name of the observed body.

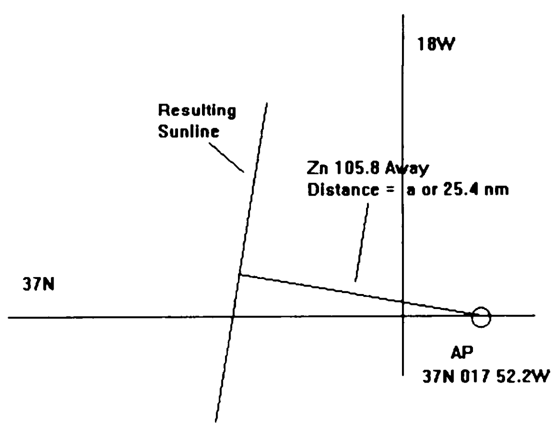

Figure 9-12. Plot the LOP.

Advancing LOPs

Advancing LOPs

Several methods may be used to advance a LOP. The most common method consists simply of advancing the AP in the direction of and for the distance of the run, as shown in figure 9-13, and drawing the new LOP.

Figure 9-13 illustrates a situation where the AP was advanced parallel to the course line for the distance run, and a new LOP was plotted from its new position. The new LOP was necessary because the same AP would have produced an LOP that would have intersected the course line beyond the limits of the chart. In this illustrative case, it is unnecessary to draw the first dashed construction on the chart.

The manner of advancing LOP from sights of the Moon, Venus, and Sirius (previously illustrated) to obtain an 1815 fix is seen in figure 9-14.

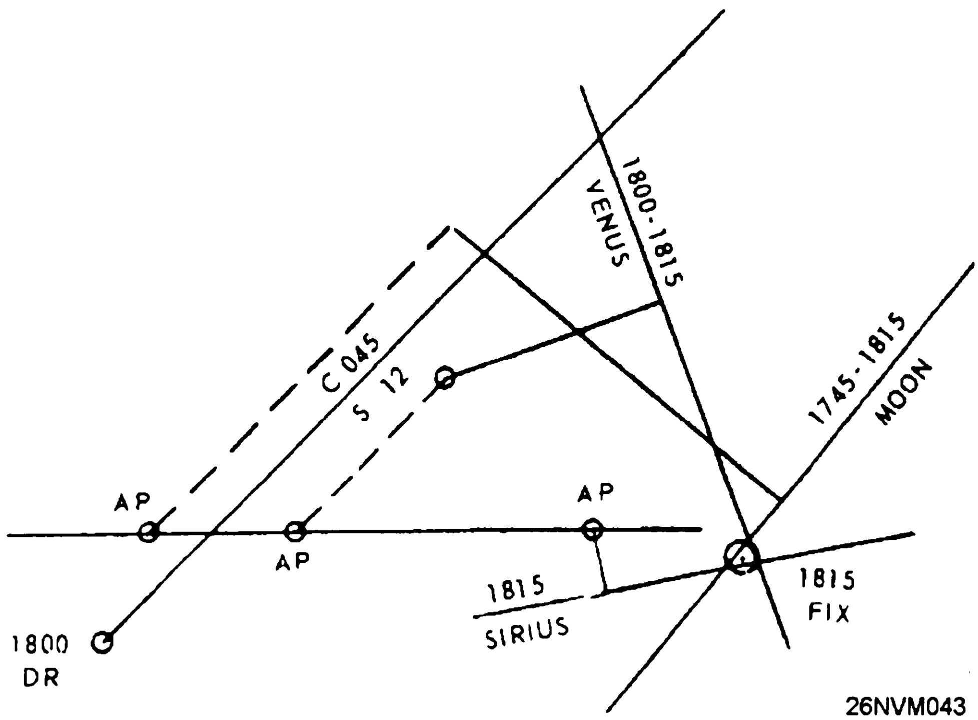

Figure 9-14. A fix from several LOPs.

Three lines of position by observation, like those obtained in piloting, do not always intersect exactly. Quite often a triangle is formed. If one or more of the LOPs must be advanced, the triangle is likely to be larger. Frequently, the center of the triangle is assumed to be the fix.

If, however, one or more lines have been advanced, more weight may be given to a line that has not been advanced, or to a line that the navigator has more confidence in; for example, favoring a first magnitude star over a third magnitude star. In figure 9-14, note that the plots are made from three separate APs, using the same assumed latitude but different assumed longitudes.

Reducing Stars, Planets, and the Moon Using Pub 229

Procedure for Stars and Planets

The steps to follow to reduce stars and planets are nearly the same steps that we used to reduce our sunline. The only differences are that in both cases when finding LHA, we must add the value of sidereal hour angle (SHA) to the total GHA to find LHA. Also, in the altitude correction tables for stars and planets there is an additional correction listed for some planets that must be added.

Procedure for the Moon

Once again the steps for the Moon are the same as our sunline except that the *v* and HP corrections must be added. These are additional altitude corrections. The *v* correction is always +. The HP correction for the nearest whole hour of GMT is selected. The v correction is found on the appropriate increments minutes and seconds page in the same manner as the *d* correction. If the upper limb of the Moon is observed, an additional correction (Add’l Corr) of -30' is made.

Reducing Sights Using Pub 249

General

HO Pub 249, *Sight Reduction Tables for Air Navigation* and the *Air Almanac*, can also be used to reduce sights. This method of sight reduction is used by some navigators; however, the degree of accuracy is slightly less than sight reduction by Pub 229.

Procedure

Once again, you would have to gather information to reduce; that is, GMT, sextant altitude, and so on.

For our example problem, we will use the following data:

Date: 30 March 1985 GMT: 06 26 21
Lat: 36° 40.1'N Long: 017° 31.6' W
hs: 40° 33.6' IC: + 0.8
Hgt of Eye: 50 ft

OPNAV 3130/32 H.O.249 Air Alm	**ACTION**	**Completed Strip Form**
Body	Enter the name of the body.	REGULUS
GMT	Enter time of sight.	06h 26m 21s
IC	Enter the index correction.	+ 0.8
D	Enter the dip correction (hgt of eye 50ft) using the altitude correction table from the *Air Almanac*. (See fig. 9-16.)	- 7.0
R *o*	This is the refraction correction from the *Air Almanac*. (See fig. 9-17.)	- 1.0
SD		
ha		
Total Corr (sum)	Total of IC, D, and R *o*.	- 7.2
hs	Enter the sextant altitude.	40° 33.6'
Ho	Apply altitude corrections to find.	40° 26.4'

CORRECTIONS TO BE APPLIED TO MARINE SEXTANT ALTITUDES

CORRECTION FOR DIP OF THE HORIZON

To be subtracted from sextant altitude

Ht.	Dip	Ht.	Dip	Ht.	Dip	Ht.	Dip	Ht.	Dip
Ft.	′	Ft.	′	Ft.	′	Ft.	′	Ft.	′
0		114		437		968		1 707	
	1		11		21		31		41
2		137		481		1 033		1 792	
	2		12		22		32		42
6		162		527		1 099		1 880	
	3		13		23		33		43
12		189		575		1 168		1 970	
	4		14		24		34		44
21		218		625		1 239		2 061	
	5		15		25		35		45
31		250		677		1 311		2 155	
	6		16		26		36		46
43		283		731		1 386		2 251	
	7		17		27		37		47
58		318		787		1 463		2 349	
	8		18		28		38		48
75		356		845		1 543		2 449	
	9		19		29		39		49
93		395		906		1 624		2 551	
	10		20		30		40		50
114		437		968		1 707		2 655	

26NVM048

Figure 9-16. Marine sextant altitude correction from the *Air Almanac.*

CORRECTIONS TO BE APPLIED TO SEXTANT ALTITUDE

REFRACTION

To be subtracted from sextant altitude (referred to as observed altitude in A.P. 3270)

R_o	Height above sea level in units of 1000 ft.												R_o
	0	5	10	15	20	25	30	35	40	45	50	55	
	Sextant Altitude												
′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	′
	90	90	90	90	90	90	90	90	90	90	90	90	
0													0
	63	59	55	51	46	41	36	31	26	20	17	13	
1													1
	33	29	26	22	19	16	14	11	9	7	6	4	
2													2
	21	19	16	14	12	10	8	7	5	4	2 40	1 40	
3													3
	16	14	12	10	8	7	6	5	3 10	2 20	1 30	0 40	
4													4
	12	11	9	8	7	5	4 00	3 10	2 10	1 30	0 39	+0 05	
5													5
	10	9	7	5 50	4 50	3 50	3 10	2 20	1 30	0 49	+0 11	−0 19	
6													6
	8 10	6 50	5 50	4 50	4 00	3 00	2 20	1 50	1 10	0 24	−0 11	−0 38	
7													7
	6 50	5 50	5 00	4 00	3 10	2 30	1 50	1 20	0 38	+0 04	−0 28	−0 54	
8													8
	6 00	5 10	4 10	3 20	2 40	2 00	1 30	1 00	0 19	−0 13	−0 42	−1 08	
9													

26NVM049

Figure 9-17. Excerpt from refraction correction tables of the *Air Almanac.*

(DAY 089) GREENWICH A. M. 1985 MARCH 30 (SATURDAY)

GMT (UT) h m	☉ SUN GHA ° ′	SUN Dec. ° ′	ARIES GHA ♈ ° ′	VENUS-4.1 GHA ° ′	VENUS Dec. ° ′	JUPITER-2.1 GHA ° ′	JUPITER Dec. ° ′	SATURN 0.3 GHA ° ′	SATURN Dec. ° ′	◐ MOON GHA ° ′	MOON Dec. ° ′
00 00	178 50.2	N 3 39.7	187 19.5	174 44	N14 10	234 09	S17 59	311 20	S17 24	82 38	N26 59
10	181 20.3	39.9	189 49.9	177 14		236 39		313 51		85 03	59
20	183 50.3	40.1	192 20.3	179 45		239 10		316 21		87 27	59
30	186 20.3	· 40.2	194 50.7	182 16	· ·	241 40	· ·	318 52	· ·	89 52	· 59
40	188 50.4	40.4	197 21.1	184 46		244 10		321 22		92 16	58
50	191 20.4	40.5	199 51.5	187 17		246 41		323 52		94 40	58
05 00	253 51.2	N 3 44.6	262 31.8	250 03	N14 07	309 19	S17 59	26 33	S17 23	154 50	N26 50
10	256 21.2	44.7	265 02.2	252 33		311 50		29 04		157 15	49
20	258 51.2	44.9	267 32.6	255 04		314 20		31 34		159 39	49
30	261 21.3	· 45.1	270 03.0	257 35	· ·	316 50	· ·	34 04	· ·	162 03	· 48
40	263 51.3	45.2	272 33.5	260 05		319 21		36 35		164 28	48
50	266 21.3	45.4	275 03.9	262 36		321 51		39 05		166 52	48
06 00	268 51.4	N 3 45.6	277 34.3	265 06	N14 06	324 21	S17 59	41 36	S17 23	169 17	N26 47
10	271 21.4	45.7	280 04.7	267 37		326 52		44 06		171 41	47
20	273 51.4	45.9	282 35.1	270 08		329 22		46 36		174 05	46
30	276 21.5	· 46.0	285 05.5	272 38	· ·	331 52	· ·	49 07	· ·	176 30	· 46
40	278 51.5	46.2	287 35.9	275 09		334 23		51 37		178 54	46
50	281 21.5	46.4	290 06.3	277 40		336 53		54 08		181 18	45
07 00	283 51.6	N 3 46.5	292 36.7	280 10	N14 06	339 23	S17 59	56 38	S17 23	183 43	N26 45
10	286 21.6	46.7	295 07.1	282 41		341 54		59 09		186 07	44
20	288 51.6	46.9	297 37.6	285 11		344 24		61 39		188 32	44
30	291 21.7	· 47.0	300 08.0	287 42	· ·	346 54	· ·	64 10	· ·	190 56	· 43
40	293 51.7	47.2	302 38.4	290 13		349 25		66 40		193 20	43
50	296 21.7	47.3	305 08.8	292 43		351 55		69 10		195 45	42
11 00	343 52.3	N 3 50.4	352 46.6	340 25	N14 03	39 31	S17 58	116 48	S17 23	241 28	N26 33
10	346 22.3	50.6	355 17.0	342 56		42 02		119 19		243 52	32
20	348 52.4	50.7	357 47.4	345 27		44 32		121 49		246 16	32
30	351 22.4	· 50.9	0 17.8	347 57	· ·	47 02	· ·	124 20	· ·	248 41	· 31
40	353 52.4	51.1	2 48.2	350 28		49 33		126 50		251 05	31
50	356 22.5	51.2	5 18.6	352 59		52 03		129 21		253 30	30
Rate	15 00.2	N0 01.0		15 03.8	S0 00.7	15 02.0	N0 00.1	15 02.6	0 00.0	14 26.3	S0 02.5*

Lat. °	Moon-rise h m	Diff. m
N		
72	▭	*
70	▭	*
68	▭	*
66	▭	*
64	▭	*
56	16 15	19
58	16 36	17
60	17 03	14
S		

Moon's P. in A.

Alt °	Cor + ′	Alt °	Cor + ′
0		55	
	57		32
5		56	
	56		31
12		57	
	55		30
16		58	
	54		29
19		59	
	53		28
22		61	
	52		27
24		62	
53			
	33		
55			
	32		
56			

Sun SD 16′.0
Moon SD 15′
Age 9d

26NVM050

Figure 9-18. Excerpt from the daily pages of the *Air Almanac.*

LAT 37°N

LHA ♈	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn	Hc	Zn
	* VEGA		Alphecca		ARCTURUS		* SPICA		REGULUS		* POLLUX		CAPELLA	
180	16 15	053	44 14	087	55 52	112	38 11	154	54 27	233	36 10	280	18 48	314
181	16 54	054	45 02	087	56 36	113	38 32	155	53 48	234	35 23	281	18 13	314
182	17 33	054	45 49	088	57 20	114	38 52	156	53 09	236	34 36	281	17 39	315
183	18 12	055	46 37	089	58 04	115	39 11	157	52 29	237	33 49	282	17 05	315
184	18 51	055	47 25	089	58 47	116	39 29	158	51 49	238	33 02	282	16 32	316
185	19 30	056	48 13	090	59 30	118	39 46	160	51 08	239	32 15	283	15 58	316
186	20 10	056	49 01	090	60 12	119	40 02	161	50 27	240	31 28	283	15 25	317
187	20 50	057	49 49	091	60 54	120	40 17	162	49 45	241	30 42	284	14 53	317
188	21 30	057	50 37	092	61 35	121	40 32	163	49 03	242	29 55	284	14 20	318
189	22 10	057	51 25	092	62 16	123	40 45	165	48 20	243	29 09	285	13 48	318
190	22 51	058	52 13	093	62 56	124	40 57	166	47 37	244	28 23	285	13 16	318
191	23 31	058	53 01	094	63 35	126	41 08	167	46 54	245	27 37	286	12 44	319
192	24 12	059	53 48	094	64 13	127	41 18	169	46 10	246	26 51	286	12 13	319
193	24 53	059	54 36	095	64 51	129	41 28	170	45 26	247	26 05	287	11 42	320
194	25 34	059	55 24	096	65 28	131	41 36	171	44 42	248	25 19	287	11 11	320
	* DENEB		ALTAIR		Nunki		* ANTARES		ARCTURUS		* Alkaid		Kochab	
255	48 32	061	42 31	116	21 18	153	26 11	188	49 49	256	53 17	306	49 39	347
256	49 13	061	43 14	117	21 40	154	26 03	189	49 03	256	52 38	306	49 28	347
257	49 55	061	43 57	118	22 00	155	25 55	190	48 16	257	51 59	306	49 17	347
258	50 37	061	44 39	119	22 21	156	25 47	191	47 29	258	51 20	306	49 05	346
259	51 19	061	45 21	120	22 40	157	25 37	192	46 42	259	50 41	306	48 54	346
260	52 01	061	46 03	121	22 59	157	25 26	193	45 55	260	50 02	306	48 42	346
261	52 44	062	46 44	122	23 17	158	25 15	194	45 08	260	49 23	306	48 30	345
262	53 26	062	47 25	123	23 34	159	25 03	195	44 21	261	48 44	306	48 18	345
263	54 08	062	48 05	124	23 51	160	24 50	196	43 33	262	48 05	306	48 05	345
264	54 50	062	48 44	125	24 07	161	24 37	197	42 46	262	47 27	306	47 53	345
265	55 32	062	49 24	126	24 22	162	24 22	198	41 58	263	46 48	306	47 40	344
266	56 15	062	50 02	127	24 36	163	24 07	199	41 11	264	46 09	306	47 27	344
267	56 57	062	50 40	128	24 50	164	23 52	200	40 23	264	45 30	306	47 14	344
268	57 39	062	51 17	130	25 03	165	23 35	201	39 35	265	44 52	306	47 00	344
269	58 22	062	51 54	131	25 15	166	23 18	202	38 47	266	44 13	307	46 46	343

26NVM052

Figure 9-19. Excerpt from Pub 249, Volume I.

OPNAV 3130/32 H.O.249 Air Alm	ACTION	Completed Strip Form
GHA(h)	Enter the GHA hour value of Aries from the *Air Almanac* to the nearest 10 minutes. (See fig. 9-18).	282° 35.1'
Increment (m/s)	Enter the minutes and seconds value from the interpolation tables of the *Air Almanac.*	1° 35.5'
Total GHA	Add GHA(h) and Increments (m/s).	284° 10.6'
+ - 360 (if needed)		
a Long (+E, -W)	Enter the assumed DR longitude to arrive at an even degree of LHA, add east and subtract west.	17° 10.6'W
LHA	LHA= Total GHA + (v/v or SHA for stars and planets) +E or -W DR Long.	267° 00.0'
a LAT	Enter the assumed latitude.	37°N
Hc	Enter Pub 249 volume I, with the whole degree of LHA for REGULUS, record Hc and Zn (last block). (See fig. 9-19.)	40° 23.0'
Ho	Drop down Ho from above.	40° 26.4'
a	Find the difference between Hc and Ho (remember to use Ho MO To). In this example, Ho is more than Hc, so it’s named T for towards.	T 3.4'
Zn	Enter the Zn (true bearing).	264°

As you can see, using Pub 249 to determine a celestial LOP is a quick process compared to using Pub 229. Keep in mind that some amount of accuracy is lost.

Latitude by Local Apparent Noon (LAN)

Time of Meridian Passage

The purpose of knowing ahead of time the exact time of meridian passage (the Sun directly overhead) of the Sun is to allow the observer and recorder to arrive on the bridge a few minutes early. A latitude line from LAN is very useful. It is often used along with two morning sunlines to establish a noon celestial running fix. We will again be using a strip form to complete our sight reduction. First, we will find the time of meridian passage, then we will work the LAN solution. For our example problem, we will use the following data: Date: 30 March 84, DR Lat: 36°36.1'N, DR Long: 19° 22.3'W.

<table>
<tr><th>OPNAV 3130/35
LAN</th><th>ACTION</th><th>Completed Strip Form</th></tr>
<tr><td>DR Long</td><td>Enter the DR longitude.</td><td>19° 22.3'W</td></tr>
<tr><td>STD Meridian</td><td>Enter the standard meridian.</td><td>15</td></tr>
<tr><td>d long (arc)</td><td>Find the difference between STD Mer and DR Long.</td><td>4° 22.3'</td></tr>
<tr><td>d long (time)</td><td>Convert arc to time using the arc to time page in the Nautical Almanac.</td><td>+ 17 Min</td></tr>
<tr><td>LMT Mer Pass</td><td>From the daily pages in the Nautical Almanac for the given date, enter the time of meridian passage (bottom right of page).</td><td>1204</td></tr>
<tr><td>ZT LAN (1st est.)</td><td><table>
<tr><th>IF...</th><th>THEN...</th></tr>
<tr><td>west of the standard meridian</td><td>Add d long (time) to LMT Mer Pass.</td></tr>
<tr><td>east of the standard meridian</td><td>Subtract d long (time) from LMT Mer Pass.</td></tr>
</table></td><td>1221</td></tr>
<tr><td>Rev.DR Long</td><td>Enter revised DR.</td><td>19° 22.3'W</td></tr>
<tr><td>STD Meridian</td><td>Enter the standard meridian.</td><td>15</td></tr>
<tr><td>d long (arc)</td><td>Find the difference between STD Mer and DR Long.</td><td>4° 40.0'</td></tr>
<tr><td>d long (time)</td><td>Convert arc to time.</td><td>+19</td></tr>
<tr><td>LMT Mer Pass</td><td>Enter LMT for Mer Pass.</td><td>1204</td></tr>
<tr><td>ZT LAN (2nd est)</td><td>Add time to LMT Mer Pass.</td><td>1223</td></tr>
</table>

Taking Sights to Observe LAN

Up to this point we have learned how to find the time that the Sun should be directly overhead. Now we need to know how to observe LAN. We will discuss two methods. The first is called following to maximum altitude; the second is called *numerous sights.*

Following to Maximum Altitude

The oldest method of determining meridian altitude of the Sun, and the one used most commonly, is known as following to maximum altitude. It is recommended because of its adaptability to various conditions, and because its use develops an insight into how the altitude varies near the time of apparent noon.

At approximately 10 minutes before watch time of LAN, the observer contacts the Sun’s lower limb with the horizon in the sextant. He/she then swings the sextant from side to side, and adjusts it until the Sun, seen moving in an arc, just touches the horizon at the lowest part of the arc. This procedure is known as swinging the arc, which was described earlier in this chapter.

As the Sun continues rising, a widening space appears between its lower limb and the horizon. By turning the micrometer drum, the observer keeps this space closed and maintains the Sun in contact with the horizon. The change in altitude becomes slower and slower, until the Sun "hangs". While it is hanging, the observer swings the sextant to make certain of accurate contact with the horizon. He/she continues the observations until the Sun dips, which is a signal that the Sun is beginning to lose altitude. The sextant then shows the maximum altitude attained.

Numerous Sights

The method of taking numerous sights is a modification of the maximum altitude method. It is useful under conditions where heavy seas, clouds, and the like may make steady observation impossible. Well before watch time of LAN, the observer begins taking a series of altitudes. Their number depends on the difficulties of the situation and the possible error in computed time of transit. He/she reads off the altitudes to a recording assistant, turning the tangent screw slightly after each observation to make sure that the next altitude is an independent sight. Observations are discontinued when the altitude definitely shows signs of decreasing.

Under favorable conditions, even a series of skillfully taken observations may show an occasional erratic deviation from the normal gradual rise and fall. After sights showing a radical difference from the preceding or succeeding series are discarded, however, the hang should become evident, and it should be possible to judge the maximum altitude. The figure selected will probably be less than the altitude shown in one observation and more than that below it. The result should give latitude with an error no more than 1'. This reading is considerably more accurate than could be obtained by a single sight under the conditions described.

Finding Latitude

As you now know, you must first obtain a sight of the Sun when it’s at maximum altitude and the time of observation. With this and a DR position, we can reduce the sight to find latitude; now we can work the second part of our strip form.

OPNAV 3130/35 LAN	ACTION	Completed Strip Form
LAT by LAN		
ZT LAN (obs)	Enter the ZT of the observation.	1221
ZD	Enter the zone description.	+ 1
GMT	Convert ZT to GMT.	1321
Tab Dec	Enter the tabulated declination for the Sun from the *Nautical Almanac*.	N 3° 57.9′
d# / d Corr	Enter the d# from the bottom of the Sun column, remember to find out if dec is + (increasing) or - (decreasing). Find the d Corr from the increments minutes and seconds pages for 21 minutes.	+ 1.0 / + 0.4
True Dec	Apply the d Corr to Tab Dec	N 3° 58.3′
IC	Enter the index correction.	+ 1.2
D	Enter the dip correction.	- 6.9
Sum	Enter the total of the IC and D.	- 5.7
Hs	Enter the uncorrected sextant altitude.	57 16.4
Ha	Apply the sum of the IC and dip corrections.	57 10.7
Alt Corr	Enter the altitude correction from the inside cover of the *Nautical Almanac*.	+ 15.6
Ho	Apply the Alt Corr to Ha.	57 26.3

Latitude by Local Apparent Noon (LAN), Continued

<table>
<tr><th>OPNAV 3130/35 LAN</th><th>ACTION</th><th>Completed Strip Form</th></tr>
<tr><td>89° 60'</td><td>Enter 89° 60.0'.</td><td>89° 60.0</td></tr>
<tr><td>HO (-)</td><td>Enter Ho.</td><td>57° 26.3</td></tr>
<tr><td>Z Dist</td><td>Subtract Ho from 89 60.0.</td><td>32° 33.7’</td></tr>
<tr><td>True Dec</td><td>Enter True Dec.</td><td>N 3° 58.3</td></tr>
<tr><td>Lat</td><td>Use the following rules for making the declination correction:
<table>
<tr><th>IF...</th><th>THEN...</th></tr>
<tr><td>Lat and Dec are of different names</td><td>Lat = Z dist - Dec</td></tr>
<tr><td>Lat and Dec are of same names and Lat is less than Dec</td><td>Lat = Dec - Z dist</td></tr>
<tr><td>Lat and Dec are of same names and Lat is greater than Dec</td><td>Lat = Z dist + Dec</td></tr>
</table></td><td>36° 32.0'</td></tr>
<tr><td>Time</td><td></td><td>12h 21m 00s</td></tr>
</table>

Closing Remarks

Celestial navigation requires skill gained through experience. This chapter has given you the basic knowledge required to meet the minimum requirements of the Quartermaster occupational standards. This is just the tip of the iceberg; you should strive to perfect your celestial skills. In the event of a large scale war, you may find that all electronic means of obtaining a fix have been knocked out. It’s important that electronic fixes are compared to celestial fixes whenever possible. Remember, the prudent navigator uses all available means to accurately fix the ship’s position along the intended track.

Quartermasters should study sources other than this RTM to gain additional knowledge on celestial navigation. *Dutton's Navigation and Piloting* is a excellent reference on this material.